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THE INFLUENCE OF CULTURAL CONDITIONS ON THE DEVELOPMENT OF *ALTERNARIA* LEAF SPOT OF CINERARIAS

By A. J. COOPER*
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THE disease of cinerarias known as *Alternaria* leaf spot was first identified in the British Isles in 1949 by Green and Hewlett (1950) from cineraria leaves received by them at the Royal Horticultural Society's Laboratory, Wisley, from four areas in Kent and one in Eire.

The fungus (*Alternaria senecionis*) infects the leaves, forming brownish-black spots of irregular shape. According to the cultural conditions under which the plant is grown and the age of the leaf attacked, these spots may or may not be surrounded by a chlorotic halo, most marked in the more mature leaves. As the disease progresses the spots coalesce until badly infected leaves are killed.

The disease was first described by Neergaard (1944), working in Copenhagen, who isolated the fungus from infected cineraria seed received from Denmark, France and Germany. He reported that under natural conditions the fungus had been recorded as causing a leaf-spotting disease of cinerarias only, but that under experimental conditions lettuces were strongly, and cucumbers, tomatoes and godetias were weakly, attacked.

RESISTANCE TO INFECTION.

The factors of the environment dealt with in this investigation, namely, mineral nutrition, soil moisture and light intensity, have had no effect on the inability of cinerarias to resist infection under conditions favourable to spore germination. Relative leaf age on the same plant also had no effect, both young and mature leaves being unable to resist infection.

There have been reports of fairly mature plants, but none of seedlings, being attacked by the fungus in the British Isles, and the work carried out at Reading showed that resistance to infection decreased significantly ($P=0{\cdot}05$) with age. The third leaf on five groups of twenty plants of different ages was inoculated with a spore suspension and the resulting numbers of infected plants are shown in Table I.

TABLE I.

Effect of age of cineraria plants on leaf infection.

Plant age in days from sowing	Number of plants infected
142	20
121	20
100	19
79	17
58	5

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These findings are in agreement with those of Riley (1949) working on *Alternaria* brown-spot of tobacco.

Effect of age of tissue on resistance to internal spread.

Although it was found that mature and immature leaves on plants of the same age were equally susceptible to infection, the subsequent rate of spread of the pathogen within the leaf tissues was different. Without exception the rate of spread was extremely slow in immature leaves, whereas mature leaves developed symptoms of the disease more rapidly. These observations are also in agreement with the work of Riley (1949) who concluded that the spread of *A. longipes* was much less in younger, than in older, leaves of the tobacco plant.

The effect of age of the plant on rate of spread of the pathogen within leaves of comparable position on the plant tended to be similar to the effect on resistance to infection. It did not, however, quite reach significance at the 5 per cent. level. The third leaf in five different age groups of twenty plants was inoculated with mycelium and the resulting mean diseased leaf areas are shown in Table II.

Table II.

Effect of age of cineraria plants on area of leaf surface invaded.

Plant age in days from sowing	Mean diseased leaf area (sq. cm.)
142	8·2
121	7·3
100	6·7
79	4·0
58	0·5

Effect of soil moisture.

The extent to which cultural conditions influenced the severity of the disease was investigated in some detail and several experiments were carried out in three different years to determine the effect of heavy as against light watering. The soil in which the heavily watered plants were growing was never allowed to dry out and the surface of the soil in the pots was kept in a permanently moist condition, whereas the plants watered lightly were watered only when it was necessary to prevent wilting, i.e., at the first sign of any loss of turgidity in the leaves. The third leaf on each plant was inoculated and the resulting diseased areas measured with a planimeter. The number of pots used in each experiment and the mean diseased leaf areas are shown in Table III.

In all the experiments, except the first, heavy watering significantly ($P=0{\cdot}05$) increased the severity of the disease.

Effect of mineral nutrition.

Preliminary manurial experiments showed that the amount of potash present in the compost in the pots had very little effect on the severity of the disease but that the amount of nitrogen and phosphate appeared to have an effect.

Table III.

Effect of amount of watering on area of leaf surface invaded.

Watering	Mean diseased leaf area (sq. cm.)				
	Exp. 1 (192 pots)	Exp. 2 (144 pots)	Exp. 3 (144 pots)	Exp. 4 (96 pots)	Exp. 5 (96 pots)
Heavy	8·6	15·4	11·3	18·3	31·9
Light	4·2	4·1	3·2	0·3	6·1

Consequently the effect of phosphatic manuring was further tested during the months of May to October. The treatments applied were based on the John Innes potting compost, the superphosphates being omitted in one treatment (P_o), added at the normal rate (P_n) and at three times the normal rate (P_{3n}). There was, however, no significant effect ($P=0·05$) on susceptibility.

The effects of three levels of nitrogenous manuring were tested during the months of February to June, with normal commercial shading applied to the glasshouse roof during the late spring. The manurial treatments were again based on the John Innes potting compost, hoof-and-horn being omitted from the compost (N_o), incorporated at the normal rate (N_n) and at three times the normal rate (N_{3n}). The third leaf on each plant was inoculated and the mean diseased leaf areas are shown in Table IV.

Table IV.

Effect of nitrogenous manuring on area of leaf surface invaded.

Nitrogenous manuring	Mean diseased leaf area (sq. cm.)
N_o	12·1
N_n	6·1
N_{3n}	3·6

The addition of hoof-and-horn to the compost at the normal rate resulted in a significant ($P=0·05$) decrease in the severity of the disease. The three-fold addition of hoof-and-horn further reduced the severity of the disease but the difference, relative to the normal addition, was not statistically significant.

The conclusion that an increase in nitrogenous manuring resulted in a decrease in the spread of the pathogen within the leaf tissue is in agreement with the findings of Riley (1949) working with *A. longipes* on tobacco, of Barratt and Richards (1944) on *Alternaria* blight of *Lycopersicon* species and of Thomas (1940) on a collar rot of tomato seedlings caused by *A. solani*.

In a further experiment all possible combinations of the high and low nitrogenous and phosphatic manuring described above were tested, the treatments being $N_{3n}P_{3n}$, $N_{3n}P_o$, N_oP_{3n} and N_oP_o. These manurial treatments were tested with two groups of plants kept heavily shaded and lightly shaded during the months of September to February. Neither the manurial treatments nor the amount of shading had any

significant effect (P=0·05) on the severity of the disease. The experiment was repeated with plants grown during the summer months of March to August. The third leaf on each of the 288 plants used was inoculated and the results are shown in Table V.

TABLE V.

Effect of manurial treatment and shading on area of leaf surface invaded.

Manurial treatment	Mean diseased leaf area (sq. cm.)	
	Heavily shaded	Lightly shaded
$N_{3n}P_{3n}$	0·8	11·9
$N_{3n}P_0$	0·3	34·4
N_0P_{3n}	5·5	15·8
N_0P_0	5·6	18·4

At the higher light intensity the nitrogenous manuring failed to have a significant effect, whereas the application of hoof-and-horn to the more heavily shaded plants significantly (P=0·05) reduced the severity of the disease. The addition of superphosphate significantly (P=0·05) reduced susceptibility in the lightly shaded plants but had little effect on those heavily shaded.

From a consideration of these two experiments it appears that there may be an interaction between the effects of manurial treatment and of degree of shading on severity of the disease, i.e. the effect of mineral nutrition may be affected by the light intensity.

The effect of liming was tested over two years in combination with both heavy and light watering. The liming treatments were again based on the John Innes potting compost, ground chalk being omitted from the compost, added at the normal rate and at three times the normal rate. In neither year did the effect of liming have any significant effect on the severity of the disease, nor was there any significant interaction between the level of watering and liming.

CONTROL OF THE DISEASE.

None of the cultural conditions studied gave increased resistance to infection and the only factor that had any effect was the age of the plant ; plants less than eleven weeks old from sowing were much more resistant to infection than older ones.

From the practical point of view it appears that, once infection has taken place, the progress of the disease can be affected to some extent by the cultural conditions under which the plants are grown. There is little doubt that, if the watering is kept as light as is possible, the severity of the disease will be reduced. Increasing either the nitrogenous or the phosphatic manuring also tends to reduce the severity, but the effect may not always occur, probably because of an interaction between mineral nutrition and light intensity. Reduction of the severity of disease by increased nitrogenous manuring of the host is not a common occurrence ; for the majority of diseases, increased nitrogen supply lowers resistance, but there are some, including several diseases caused by species of *Alternaria*, in which the resistance of the host plant is increased by an increase in its nitrogen supply.

The third practical observation which emerged from the work is that varying the lime content of the potting compost over a wide range has little effect on the severity of the disease.

SUMMARY.

1. Both mature and immature leaves of cineraria were susceptible to infection by *Alternaria senecionis* but the subsequent rate of spread of the pathogen within the leaf tissue was more rapid in mature leaves.

2. A high soil moisture content increased the rate of spread of the pathogen within the leaf tissue.

3. The levels of nitrogenous and phosphatic manuring affected the rate of spread, subsequent to infection, within the leaf tissue, and there was evidence of an interaction with light intensity.

4. The lime content of the potting compost had no effect on the rate of spread.

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The writer wishes to express his gratitude to Professor R. H. Stoughton for his help and guidance throughout the work.

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A HISTOLOGICAL STUDY OF THE DEVELOPMENT OF SUPERFICIAL SCALD IN GRANNY SMITH APPLES

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THE development of the physiological disorder known as superficial scald, which results in browning of the skin of apple fruits during storage at low temperature, is of considerable economic importance. The disorder has been so termed as only the tissue immediately beneath the epidermis of the fruit shows evidence of scalding. Tissue browning does not extend into the apple flesh. The extent and the severity of scald development at low temperatures vary with the season, with the maturity of the fruit and with the length of time in storage. Immature fruits are very susceptible to scalding.

Superficial scald first appears as light brown patches on the apple skin after several months' storage at low temperature. The affected areas become deeper brown and sunken with continued storage and their extent may increase, so that at the end of storage practically the whole skin surface may be brown. Frequently, fruit which appears normal after several months in store will develop scalded areas within a few days after removal to room temperature.

Since 1903 there has been much literature on this disorder, concerned mainly with the factors influencing scald development and with attempts to prevent or delay its appearance. No detailed account of the changes occurring in the cells of apple tissue during scald development has been found. Fidler (1950) reported that the epidermal cells and occasional hypodermal cells were browned in slight scald development. He also found that the number of layers of the hypodermis showing browning increased with increasing severity of the disorder until, in severely scalded areas, the cells of the epidermis and the hypodermis were dead and collapsed ; some underlying cells of the cortical parenchyma were also dead.

Histological investigations were carried out during the 1952 and 1953 seasons with the variety Granny Smith, a green apple very susceptible to scald development. The object was to examine changes, if any, in the cells beneath the epidermis prior to the appearance of the macroscopic symptoms of scald and to follow tissue changes in the successive stages of scald development. If histological evidence of scald could be found in a fruit which appeared normal after several months in storage, it might then be possible to identify skins which would develop scalded areas on removal to normal temperature. Tetley (1931) gave a general background to the histological investigations.

MATERIAL AND METHODS.

Source of material.

Nine bushel cases of Granny Smith apples in size-classes $3\frac{1}{8}$, $2\frac{7}{8}$, $2\frac{3}{4}$, $2\frac{5}{8}$ and $2\frac{1}{2}$ in. diameter were picked on 13th March 1953, 5 weeks prior to commercial picking,

from the Bathurst Experimental Farm, Bathurst, N.S.W. It was expected that this immature fruit would develop considerable scald and a range in fruit size was selected to allow for any effect of this on the liability to scald. In addition, two cases of fruit of normal maturity ($2\frac{7}{8}$, $2\frac{5}{8}$ in. diameter) were obtained from the same source on 25th April 1953.

Storage of experimental material.

All fruit was stored at 0° C. Most was unwrapped, in order to promote scald, but a small proportion of the fruit from each case was individually wrapped in two oiled wraps as a control measure. The fruit was left undisturbed until 13th August 1953, i.e. 5 months after picking the immature fruit (13th March 1953) and approximately 4 months after the commercial picking (24th April 1953).

Examination of stored material for scald development.

Six unwrapped fruits, removed from each size-class after five months at 0° C., showed no macroscopic signs of scald but, after four days at normal temperature, scald had developed to varying degrees (Table I).

TABLE I.

Incidence of superficial scald in Granny Smith apples.

Date of picking	Fruit size (diameter in.)	Size of sample	Superficial scald		
			Nil	Slight	Moderate to severe
13.3.53 ..	$3\frac{1}{8}$	6	0	5	1
	$2\frac{7}{8}$	6	1	1	4
	$2\frac{3}{4}$	6	0	3	3
	$2\frac{5}{8}$	6	0	4	2
	$2\frac{1}{2}$	6	0	2	4
24.4.53 ..	$2\frac{7}{8}$	6	6	0	0
	$2\frac{5}{8}$	6	6	0	0

It was thus possible at this stage to obtain material which appeared normal in storage, but which would develop patches of scald when removed from storage and held at higher temperatures. Samples of such fruit were removed from storage on 19th August 1953 for histological use while the remainder of the fruit was left in undisturbed storage. The latter developed scald of varying intensity during the next four months at a temperature of 0° C.

Selection of material for histological use.

The following types of material were available during the storage period in living and fixed conditions : (1) normal tissue from the fruit stored in oiled wraps and (2) tissue showing scald development in all stages from the very slight to the very severe condition. A third type of tissue, in which the skin was known to be affected although the fruit still appeared normal, was available as fixed material only (Type 3).

The tissue for histological study was cut from the fruits so as to include the epidermis and part of the underlying flesh. Formalin-acetic alcohol (70 per cent. ethyl alcohol, 90 c.c. ; glacial acetic acid, 5 c.c. ; formalin, 5 c.c.) and osmic-chromic acid (1 per cent. osmic acid, 45 c.c. ; 2 per cent. chromic acid, 12 c.c.) were both used as fixatives.

The material of Type 3 was selected as follows : 120 fruits were removed from store and each apple was numbered with a label attached to its shoulder. Four rectangular pieces of apparently normal tissue, approximately $\frac{1}{4}$ in. $\times \frac{1}{2}$ in., were cut from each fruit and identified in an anticlockwise direction from the label as a, b, c, and d. As initial scald development had previously been observed to be patchy and could develop first at either the stem or the calyx end of the fruit, the position of the cut areas was varied ; in some fruits the pieces were taken from an equatorial position, in others from either of the ends of the fruit. The pieces of removed tissue were each placed in a separate tube of formalin-acetic alcohol and were kept until it was known whether the tissue had been derived from an area of the fruit which later developed skin browning on being held at room temperature.

The holes made in the apple flesh were sealed with melted paraffin wax and this, as a rule, prevented or sufficiently retarded fungal growth. These fruits were then held at 20° C. and examined daily for macroscopic signs of scald. If the entire area of skin surrounding a sealed hole in the fruit became scalded, the piece of tissue previously removed from that hole was considered to have been damaged and was retained for later examination. Only 15 per cent. of the pieces removed from the 120 fruits were kept as definitely having damaged cells beneath the epidermis.

Preparation of material for microscopic examination.

Hand sections of living material (Types 1 and 2) and fixed material (Types 1, 2 and 3) were cut during the investigation. These were stained either with gentian violet or with methylene blue or were mounted unstained in glycerine jelly. Fixed material was also embedded in paraffin wax and microtomed at 12μ. These sections were stained with gentian violet or Heidenhain's iron haematoxylin and permanently mounted. Sectioned tissue which had been darkened by osmic acid fixative was bleached, prior to staining, in one part hydrogen peroxide in ten parts 70 per cent. alcohol.

Microscopic examination of Granny Smith apple tissue.

The microscopic observations reported here were made on both living and fixed material which was cut in transverse section to include the epidermis and part of the underlying flesh.

Normal tissue (Type 1).

This is illustrated in Fig. 1. The epidermis of the Granny Smith apple consists of a single layer of cells approximately 17μ × 27μ in size ; they are elongated tangentially and their contents are granular and appear grey in colour. The epidermis is covered by a waxy cuticle which is approximately 16μ thick. The hypodermis is made up of five, sometimes six, layers of cells ; these cells contain numerous chloroplasts and are approximately 18μ × 15μ in size. They are elongated tangentially, have thick walls and are closely packed together. The 2–3 layers of cells of the outer cortex immediately beneath the hypodermis are made up of larger rounded cells

PLATE I

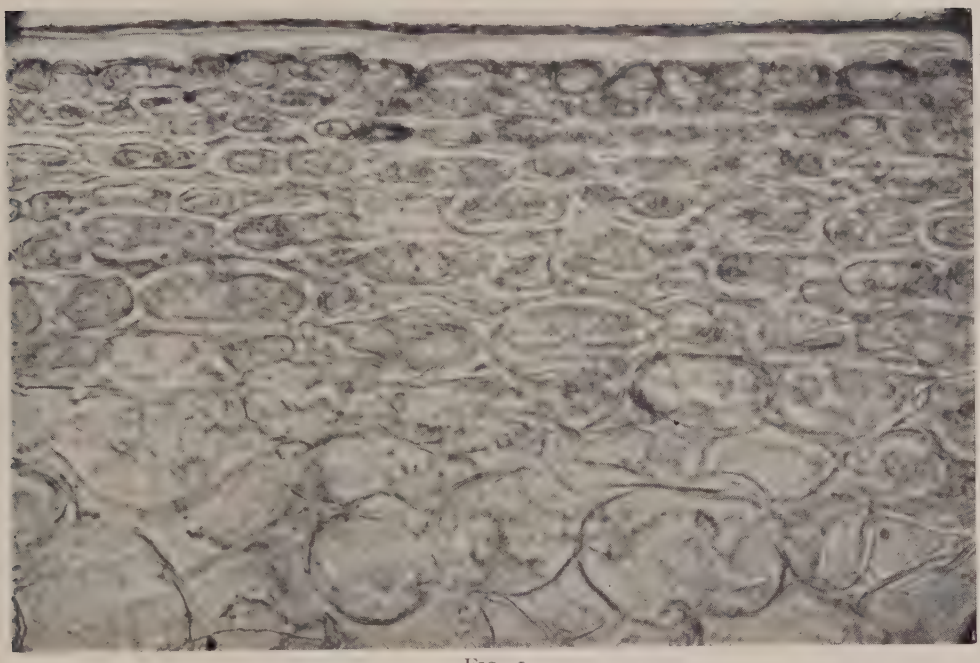

Fig. 1.

Transverse section (×240) of normal Granny Smith apple tissue showing : a, waxy cuticle ; b, epidermis ; c, hypodermis ; d, outer cortex ; e, cortex or flesh of the apple.
Material was fixed in formalin-acetic alcohol, hand sectioned, stained in gentian violet and mounted in glycerine jelly.

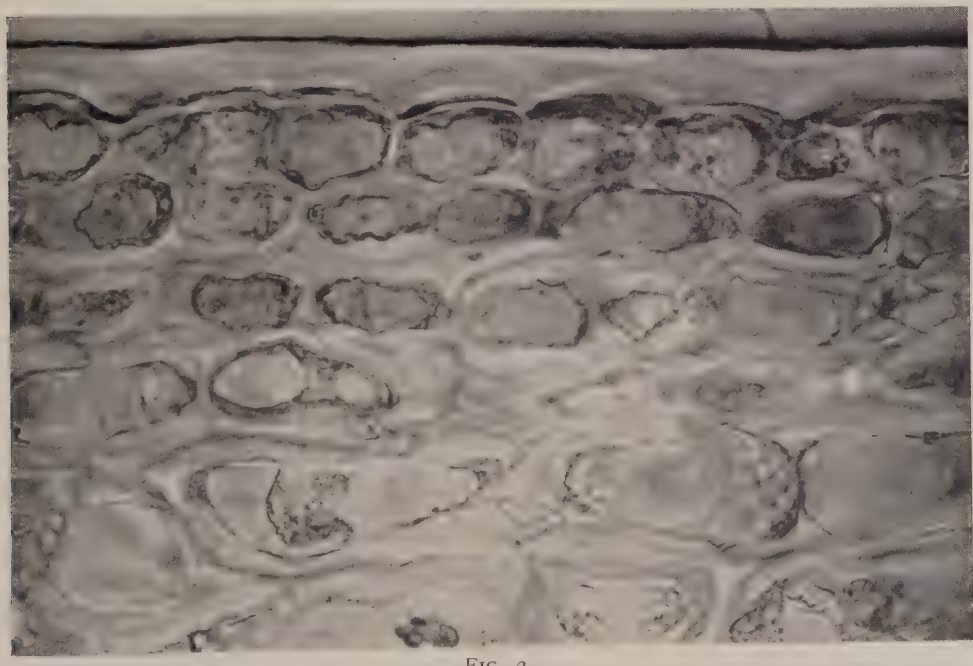

Fig. 2.

Transverse section (×535) of slightly scalded Granny Smith apple tissue showing browning of the cell contents in the two outer layers of the hypodermis (c_1). The contents of the injured cells remain intact when sectioned. The cells of the epidermis (b) and the inner hypodermis (c_2) show no indication of browning.
Material was fixed in formalin-acetic alcohol, hand sectioned and mounted unstained in glycerine jelly.

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FIG. 3.
Transverse section (×120) of Granny Smith apple tissue showing increasing severity of scald development. Cell browning extends through the layers of the hypodermis (c). The underlying outer cortical cells (d) appear normal.
Material fixed in formalin-acetic alcohol, hand sectioned, mounted unstained in glycerine jelly.

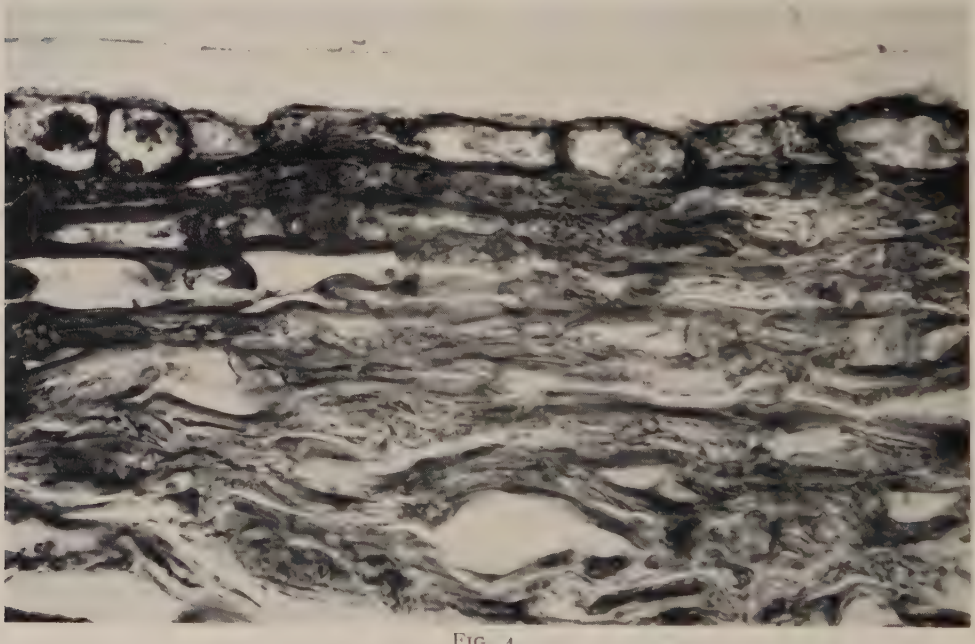

FIG. 4.
Transverse section (×535) of severely scalded and sunken tissue of a Granny Smith apple. The contents of all cells of the hypodermis (c) are brown and the cells have collapsed radially. The underlying cells of the outer cortex (d) have also collapsed.
Material fixed in osmic-chromic acid fixative, microtomed at 12μ, stained with Heidenhain's iron haematoxylin, mounted in Euparal.

with somewhat thickened walls ; they contain fewer chloroplasts than the hypodermal cells and have larger air spaces between them. These cells gradually merge into the parenchyma tissue of the cortex (flesh) which is made up of large colourless thin-walled rounded cells with a system of continuous air spaces. The outer layers of cortical cells contain a few chloroplasts.

Tissue showing successive stages in scald development (*Type 2*).

Observations made on tissue which had developed very slight scald showed that the pale brown discoloration of the skin was due to the browning of the cell contents of only the outer layers of the hypodermis (Fig. 2). The cell contents of successive layers of the hypodermal cells became brown with increasing severity of the disorder (Fig. 3). In very severely scalded tissue, the cell contents of the entire hypodermis were observed to be brown and the sunken appearance of the scalded area was seen to be due to the radial collapse of the hypodermal cells and the underlying cells of the outer cortex (Fig. 4). It was difficult to determine whether the contents of the outer cortical cells had been affected by severe scalding because the cells had collapsed; in some instances there seemed to be slight browning of the contents of the collapsed cells. The epidermis did not usually show any sign of injury or collapse although patches of brown epidermal cells were sometimes found in badly scalded areas. This last observation appears to be contrary to that of Fidler (1950) who states that epidermal and occasional hypodermal cells were brown in tissue of the King Edward VII apple which was showing " bronzing ", i.e. slight scald development, and that the epidermal cells had collapsed in severely scalded tissue.

Tissue scalded in storage but showing no macroscopic signs of disorder (*Type 3*).

When the cells of tissue, known to have been damaged in cold storage but as yet showing no macroscopic signs of scald development, were examined and compared with those of normal Granny Smith apple tissue, no differences could be detected. It was noted, however, that the contents of the " scalded " hypodermal cells stained more deeply with methylene blue and that they did not tear so easily on sectioning.

Condition of chloroplasts in tissue showing scald development.

Since the damaged cells were mainly confined to those containing many chloroplasts, it was considered that the cell browning might be related to the breakdown of chloroplasts. However, observations made on chloroplasts, extracted from slightly scalded tissue by grinding with sand in a weak sugar solution, failed to show any trace of disorganization. Sections of slightly scalded tissue showed apparently normal disc-like green chloroplasts in the pale brown cell contents of the outer hypodermis.

SUMMARY.

1. The development of superficial scald in Granny Smith apples, during or after storage at low temperature, is due to the progressive browning of the contents of the cells of the hypodermis. In slightly scalded fruit, contents of the outer hypodermal cells are light brown while the inner adjacent cells appear to be normal. With increasing severity of the disorder, the light brown colouring of the skin deepens and the browning of the cells increases in intensity and extends through the five

or six layers of the hypodermis. The epidermal cells are not affected unless the disorder is very severe ; when this occurs, groups of epidermal cells may become brown.

2. In severely scalded fruit, the affected cells of the hypodermis collapse in a radial direction so that the brown area becomes sunken. The cells of the outer cortex also become distorted but the shape of the epidermal cells is not affected.

3. Cell browning is associated with cells containing numerous chloroplasts but does not appear to be caused by disorganization of these bodies.

4. There was no evidence of any histological changes in the tissue prior to the appearance of the macroscopic symptoms of superficial scald, except for a slight difference in intensity of staining with methylene blue.

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INVESTIGATIONS ON THE CONTROL OF THE FRUIT TREE RED SPIDER MITE, *METATETRANYCHUS ULMI* KOCH

II. CONTROL BY DELAYED-DORMANCY PETROLEUM

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THIS is the second of a series of papers describing investigations extending over a ten-year period on the control of the Fruit Tree Red Spider Mite. In the initial investigations carried out in 1944 (Austin and Massee, 1947), February and March applications of petroleum were shown to be more toxic to the winter eggs of the mite than similar washes applied in January. Further, in the trial conducted at Porter's Farm, Great Braxted, Essex, the March application of petroleum was superior to either of two made earlier in the season. It was decided, therefore, to undertake a new trial designed to determine the toxicity to the winter eggs of petroleum applied at the delayed-dormancy period, mid-March, and to compare miscible and stock emulsion petroleum sprays at concentrations of three and five per cent. of the actual oil.

This modified trial was started in the winter of 1944–45 and continued for three years.

THE FIELD EXPERIMENT.

The orchard, located at the Essex Institute of Agriculture, Writtle, near Chelmsford, Essex, consisted of 470 twelve-year-old Worcester Pearmain trees, interplanted with Laxton's Superb as pollinator at one in nine.

The lay-out permitted of an arrangement of twenty-four plots, each of approximately twenty trees, providing five replicates of four treatments laid out in randomized blocks, with four additional control plots. The records were obtained from four trees selected from the inner six of each plot, the remainder serving as guard trees.

Routine spray treatments.

The orchard was sprayed with six per cent. " Standard " tar wash in the last week of December 1944 to control aphids and apple sucker. In addition the trees received routine applications of wettable sulphur at 0·5 per cent. to control apple scab, nicotine and lead arsenate to control apple sawfly and codling moth, and DDT dusts at the end of March in 1946 and 1947 to control apple blossom weevil.

Spray materials.

The commercial product from which the miscible petroleum washes were prepared contained, in addition to alkaline ammonia casein emulsifier, petroleum oil of the following specification :

Specific gravity :	0·92 at 15·5/15·5° C.
Viscosity :	200 secs. Redwood 1 at 70° F.
Unsulphonated residue :	75 per cent.
Distillation :	10 per cent. distilled at 353° C., 50 per cent. at 375·5° C., 80 per cent. at 395° C.

Sufficient bulk of oil was set aside to enable the same oil to be used throughout the trials.

The diluted washes, miscible and stock emulsion alike, contained 3 or 5 per cent. oil by volume, thus simplifying measurement of the required quantities in the field.

In 1944–45 the miscible petroleum concentrate was very viscous, coming from the drums in large clots, and could be dispersed only with difficulty ; nevertheless, satisfactory emulsion was finally obtained.

Application of experimental sprays and stages of bud development.

All the experimental sprays were applied to the plots on the same day in each of the three seasons, as follows :

Date of spray application		Bud stage
1945	13th March	Between delayed-dormancy and swelling, with a few buds breaking
1946	14th March	Delayed-dormancy
1947	17th March	Dormant stage

A mobile spraying machine was used, providing a pressure of 400 lb. p.s.i. and fitted with two lances, each with double nozzles and No. 2 discs with six-hole swirl plates ; the sprays were applied by the farm spraying team, under constant supervision. About 300–350 gallons was applied per acre on each occasion. Screens of water-proofed hessian, similar to those used in earlier trials (Austin and Massee, 1947) were used to minimize spray drift. These screens were essential in 1945, because windy conditions prevailed when the washes were applied. The hessian screens proved to be both light and portable and were preferable to the heavier screens used in other trials.

Mite population sampling.

The technique employed for obtaining samples of the mite population in the field has been described (Austin and Massee, 1947). A sample of sixteen basal rosette leaves was picked at random from each of the four " record " trees of each plot, and an " imprint " record of the mites and eggs was made in the field (Pearce, 1947 ; Freeman and Hall, 1955). The dates on which these samples were taken were determined by observing the hatch of winter eggs. Shoots bearing numbers of winter eggs were brought into the laboratory as soon as hatching started, and a record obtained, by the aid of a binocular microscope, of the percentage hatch of winter eggs. The records were supplemented by field observations, and by these means the peak hatch of winter eggs was determined.

Records.

Hatching of winter eggs was first noted on 18th April in 1945, on 4th May in 1946 and on 3rd May in 1947. The first summer eggs were noted on 7th May, 1st May and 27th May respectively.

Mite dispersal within the plots was observed each year, particularly in the hot dry weather of 1947. Each season, however, the population records were obtained before mite dispersal was recorded.

The only important predator noted during the three seasons was the Black-kneed Capsid, which was plentiful each July, and in 1947 large populations were present on all the treatments.

Bronzed foliage caused by the mites was first seen in late June and early July each year. At first it was more pronounced on control than on sprayed trees, but the difference decreased as the season progressed. Records of the Fruit Tree Red Spider Mite were taken in May 1945 and 1946 and in June 1947 ; the figures are given in the following Table.

Table I.

Red Spider populations—means per leaf.

		Mites					Eggs				
		18.5.45	16.7.45	30.5.46	2.8.46	3.6.47	18.5.45	16.7.45	30.5.46	2.8.46	3.6.47
Stock emulsion	3%	1·1	1·6	5·2	39	7·9	0·3	4·2	0·08	87	2·3
,, ,,	5%	0·7	1·5	3·3	37	8·8	0·3	4·3	0·04	70	2·4
Miscible oil	3%	0·9	0·6	4·6	50	8·5	0·3	1·5	0·07	98	2·8
,, ,,	5%	0·6	0·7	2·8	44	8·4	0·2	2·3	0·02	72	2·4
Unsprayed		4·7	3·3	16·0	33	19·2	1·6	8·0	0·3	62	3·9

In 1945 the May figures confirmed that the only significant differences in eggs were between sprayed trees and controls, but for mites lower populations were found with the stronger sprays. In July there were no significant differences for eggs amongst the treatments or between the treatments and controls, though the trends were the same as for mites ; for mites, however, there were lower populations with the miscible oil than with stock emulsion or with unsprayed, these two also differing. The mite figures on the treated plots confirm the observations made in the field, namely, that the delayed dormancy sprays, at both strengths and formulations, reduced the percentage hatch of winter eggs, thus preventing the occurrence of large mite populations early in the season and delaying leaf bronzing.

In 1946 the only differences observed in May were between the treatments and the controls ; the effect of strength was not quite significant for mites and less marked for eggs. In August no differences were observed. The populations of the first generation of summer eggs were small on both treated and untreated plots at the end of May, but by August large populations of eggs and mites were seen on all plots and the marked differences noted earlier levelled out, leaf bronzing being generally conspicuous by the end of the summer.

In 1947 there were lower populations of mites on the treatments than on the controls, and the figures for each treatment at both concentrations differed significantly from the controls but not amongst themselves.

At the time of the early summer sampling, the summer egg population on the sprayed trees was less than half that of the controls, but a record made in August showed that the populations had largely levelled up on all plots whether sprayed or not. The reduction of hatch of winter eggs by spray treatment was much less in 1947 than in the two previous seasons, and population build-up started earlier.

In 1947 the spray applications followed immediately upon the severe winter weather experienced earlier in the year, and possibly the development of the winter eggs was less advanced. It seems likely that the state of egg development at the time of spraying may influence the degree of control obtained.

There were no significant differences in crop weight on these plots in 1945 and 1946, but in 1947 there were heavier crops on the treated plots than on the controls. There was, however, no difference between the various treatments. The average weights of fruits picked in 1947 were : from sprayed trees, 105 lb. per tree : from unsprayed controls, 79 lb. per tree.

SUMMARY.

A trial of delayed-dormancy petroleum ovicides, to compare stock emulsion and miscible sprays, applied in mid-March is described.

The results show that both stock emulsion and miscible petroleum applied in mid-March at three and five per cent. considerably reduced the hatching of the winter eggs, and that the initial populations of the mites and summer eggs on the treated plots were considerably depressed when compared with the numbers on the control trees.

The populations of mites and eggs associated with either treatment and either concentration increased as the season proceeded, and at the end of July the populations of treated and control plots evened out, showing that the effect of the delayed-dormancy washes lasted only for about three months.

The Black-kneed Capsid was the only predator noted in numbers on the experimental trees and, since the immature stages of this bug were not present until the mite population records had been made, this insect did not influence the results.

Mite dispersal did not occur until late in the season, by which time the mite populations of the various treatments had levelled up.

In two years out of three there were no significant differences in the crop weights of treatments and controls ; in the third season the crop weights of the treatments were heavier than those of the controls, but the former did not differ amongst themselves.

ACKNOWLEDGMENTS.

The investigations were carried out under the auspices of the A.R.C. Technical Conference on the Red Spider Mite, upon which were representatives of the Pettar Society of Winter Wash Manufacturers and of the Ace Growers of Essex. The Writtle orchard was placed at our disposal by the Governing Body of the Essex Institute of Agriculture and by Mr. O. G. Dorey of the Essex War Agricultural Committee.

The lay-out of the trial was prepared by the Statistics Section at East Malling, who also analysed the data.

The authors wish to express their thanks to all concerned with the trial.

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THE EFFECT OF MICROCLIMATIC TEMPERATURE UPON THE DATE OF FLOWERING OF THE APPLE

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THE amount of damage done to a fruit plant in a spring frost depends upon the state of advancement of the flowers and upon the temperature they reach, both of which factors may be influenced by the microclimatic environment of the tree. The present work deals with the effect of siting upon the rate of advancement towards flowering.

Spring temperatures are well known to affect date of flowering, and Brown (1940) observed year-to-year differences of up to twenty-three days in the time of flowering of particular apple varieties. Temperatures in March were found to be more important than those in April in determining flowering dates. The varietal order of blossoming was usually very consistent. Brown (1943), working on pears, suggested a correlation between date of flowering and the spring accumulated temperatures above 43° F. Herbst and Weger (1940) had reached a similar conclusion for pears, although in years of exceptional delay " the inherent periodicity " of the tree became manifest and blossoming occurred before the appropriate temperature sum had accumulated.

Maclagan (1933) recognized in each year three time periods during which the temperature had an effect upon the subsequent date of flowering of various plants. One of these came after petal fall (presumably at the time of flower initiation) and Pearce and Preston (1954) observed a similar phenomenon in the apple. However, unlike Maclagan, they found that a hot June delayed blossoming in the following year. No direct experiments have hitherto been carried out to test this point.

The probable influence of microclimatic temperature differences upon the date of flowering of fruit trees was observed by Alter (1912) and Young and Baughman (1936) but had not been confirmed experimentally. Balchin and Pye (1950) showed that many native British plants were delayed in flowering when sited in a valley, and the best correlation between phenological observations and temperature measurements was obtained with night minima ; day maxima, accumulated temperatures above 42° F. and mean temperatures were much less significant in their effect.

EXPERIMENT I, 1954.

Siting.

Two sites, about 570 yards apart, were compared. Site X was at 202 ft. above mean sea level, in a donor area for cold air. It was sheltered on the north and west and sloped gently to the south and east. The surface was kept cultivated and consolidated throughout the experiment. Site Y was in a " frost pocket " at 134 ft. above M.S.L. and lower than any land immediately surrounding it. It was sheltered on the south-east and east, and the land to the north and west sloped upwards steeply. The surface was covered with grass and a thick layer of straw was applied in order to reduce further the night minimum temperatures in the air near the ground. Grass eventually grew through the straw and was mown periodically.

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Materials.

Three kinds of apple tree were available ; 2-year-old Cox's Orange Pippin on M.IX, 2-year-old Worcester Pearmain on M.IX and 1-year-old Cox's Orange Pippin on M.II. The two-year-old trees had been planted in 10 in. pots of JIP_2 as maidens in winter 1952–53 and pruned to nine buds above the union. They were subsequently undisturbed and unpruned (apart from the removal of any diseased wood). The maiden trees were planted in tins (approximately 9 in. cubes) of JIP_2 on 9th March 1954 and received no pruning treatment. The tins were painted and fitted with lids, and had thirteen holes ($\frac{3}{8}$ in. diameter) in each of two opposite faces.

Layout.

Eight trees of Worcester and eight of Cox in pots were placed at each site. The pots were sunk to their rims, 4 ft. apart, and arranged at random in a square 12 ft. × 12 ft. Six Cox trees in tins were also placed at each site, and the tins were turned on their sides so that the trees grew horizontally, 30 in. apart, supported on wooden pegs and at a nominal 4·5 in. above the ground. This was to ensure that all buds on a tree were subjected to much the same nocturnal temperature treatment, so that the maximum of information might be obtained from the minimum number of plants. The laying out of the experiment was completed on 11th March 1954.

Management of the trees.

The tins containing the horizontal trees were turned through 180°, once every week during the growing season, to prevent upward growth of the apical shoot. Each tin was supplied with water through its uppermost perforated face by means of trickle irrigation from a tank and no further fertilizers were supplied after planting. The trees in pots were watered by hand and were supplied with 4 gm. each of J.I. base on 28th June and 29th July 1954.

Pests and diseases were controlled by an orthodox spray programme. There was some evidence that the application of DNOC and petroleum (on 24th March) affected the breaking of the buds, particularly those of Worcester. The data obtained from the latter were consequently very variable. One Worcester and one Cox were seriously affected by bud sealing due to the oil spray, and on 15th June one Worcester was found to have died owing to the activities of a shot-hole borer. The records from these three trees were discarded.

Measurements.

For the trees in pots, bud growth was assessed with the aid of the chart given in " Fruit Bud Development " (Bull. 137 of the Ministry of Agriculture, Fisheries and Food). A scoring system was used, points being assigned as follows :

breaking and burst, 1 ; mouse ear, 2 ; green cluster, 3 ; pink bud, 4 ; flowering, 5 ; petal fall, 6.

In this first year the methods used proved not altogether satisfactory. Thus, instead of assessing the behaviour of a few selected buds on each tree, all the buds, both terminal and lateral, which had reached a given stage were counted. The number of buds varied considerably from tree to tree. Furthermore, each assessment of the state of the trees was based upon a different criterion ; thus on 25th March the total scored by all the buds on each tree was counted, whereas on 30th April only those buds which had reached green cluster or pink bud were considered. The only

consistent way, therefore, of expressing the results is to state which site was the more advanced at a particular time as judged by the criterion adopted at that time. The level of statistical significance reached gave an indication of the magnitude of the difference.

Some flower trusses were killed by frost between 30th April and 11th May. It was assumed that these were the most advanced and, for the subsequent assessments, they were counted as having reached petal fall. After flowering the amount of extension growth made by the trees was used as a standard of comparison.

The horizontal trees bore no fruit buds in this first year, but since Rogers (1953) has noted a correlation between late leafing and late flowering, vegetative growth was used as a standard of comparison ; first the number of buds breaking, then the number of leaves expanded, and finally the amount of extension growth were observed. Extension growth was measured to the nearest cm.

At each site two minimum thermometers and one maximum thermometer (all unscreened) were placed at 18 in., and a similar set at 4·5 in., above ground level. They were read daily. Form M.O.3300 (published by the Meteorological Office) was used to calculate accumulated temperatures above and below 42° F. Although this method is intended for use only with readings from screened instruments, it was adopted because it is simple and widely used.

Results.

The results from the different varieties were analysed separately because of the differences in variability of the material. In Table I the level of statistical significance attained by the difference between the measurements at the two sites is given. The numerical value of the difference has no meaning by itself, for the reasons stated earlier.

After 5th July, no further significant differences between the sites were observed, although measurements of extension growth of the upright trees were continued

Table I.

Effect of first year's siting treatment on advancement of growth.

Date 1954	Cox on M.IX		Worcester on M.IX		Cox on M.II	
	Criterion	Site more advanced	Criterion	Site more advanced	Criterion	Site more advanced
25th March	F	X*	F	N.S.	—	—
1st April	F	N.S.	F	N.S.	—	—
8th April	F	X*	F	N.S.	—	—
15th April	F	X***	F	N.S.	V	X*
23rd April	F	N.S.	F	N.S.	V	X*
30th April	F	X*	F	N.S.	V	X**
11th May	F	N.S.	F	N.S.	V	X***
19th May	F	X*	F	N.S.	V	X*
31st May	—	—	F	Y*	V	N.S.
15th June	V	N.S.	V	Y**	V	Y*
5th July	V	N.S.	V	N.S.	V	Y*

*, $P<0.05$; **, $P<0.01$; ***, $P<0.001$; N.S., no significant difference.
F, growth of fruit buds ; V, vegetative growth.

until 20th October. Measurements on the horizontal trees were terminated earlier (25th August) owing to the incidence of severe scab and canker.

The intention was to relate the growth of the horizontal trees to the temperatures at 4·5 in., and that of the upright trees to those at 18·0 in. However, the only difference between the two sets of readings was that maxima and minima were more extreme at 4·5 in. than at 18·0 in., so that more day degrees were accumulated both above and below 42° F. at 4·5 in. at each site. Figs. 1 and 2 show the accumulated temperatures and the 7-day sliding mean temperatures at 4·5 in.

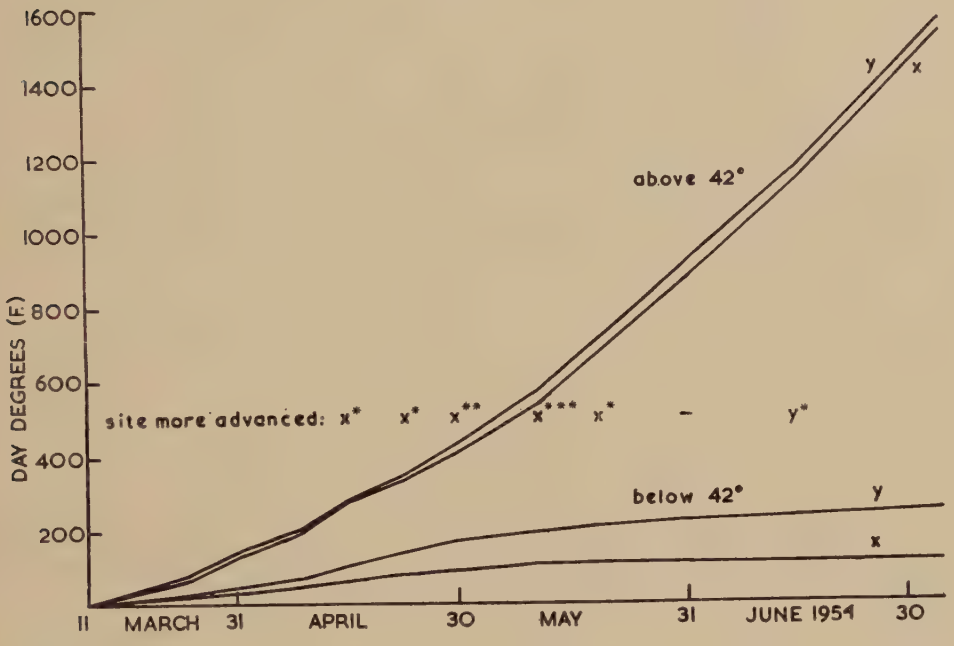

Fig. 1.

Accumulated temperatures at 4·5 in. above ground level, 1954.

Accumulated temperatures above 42° F. show little difference between the two sites (in fact, slightly favouring site Y), but there is a marked difference between the amounts accumulated below 42° F. at the two sites and between the minimum temperatures. The data from the horizontal trees (Cox on M.II in Table I) are superimposed on Fig. 2, and it seems that in spite of the more favourable day temperatures at Y the trees at this site were checked until the night minima rose above a certain level. Subsequently, the trees at Y actually became the more advanced, but the difference soon became non-significant and by the end of the growing season was negligible.

The numbers of fruits at the two sites were counted on 15th June and 20th August 1954 and are recorded in Table II.

The number of fruits per tree reaching maturity was small for both varieties, but the set on Worcester cannot be neglected and the difference between sites

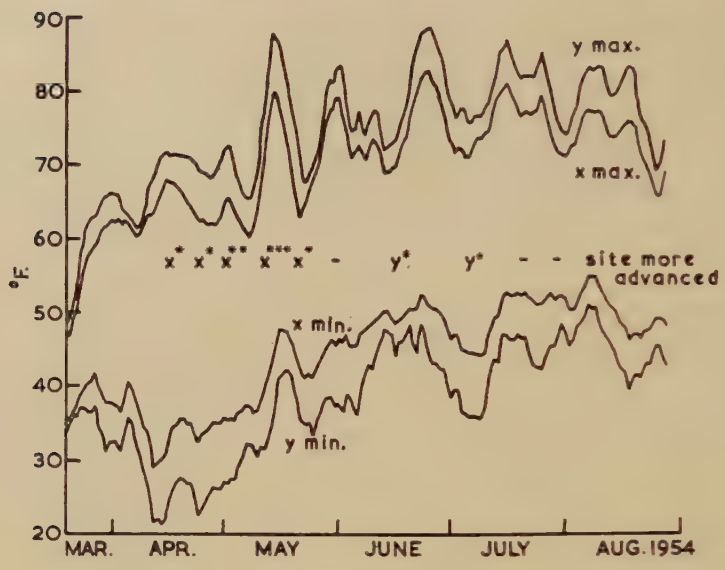

FIG. 2.

Sliding mean temperatures (7-day mean) at 4·5 in. above ground level, 1954.

TABLE II.

Effect of siting upon number of fruits.

Variety	Site	Count on 15th June (8 trees)	Count on 20th August (8 trees)
Cox	X	13	1
Cox	Y	0	0
Worcester	X	95	29
Worcester	Y	63	10

in this respect may have contributed towards the effects upon vegetative growth shown in Table I.

Although the exact date of first flowering was not noted, both Cox and Worcester had begun to flower at site X by 11th May, when the number of day degrees accumulated above 42° F. at 18 in. since 11th March was 493. The figure given by Herbst and Weger (1940) for pears was 253 day degrees above 42·8° F. The small difference in choice of datum is probably offset by the fact that their figure includes the period from 1st January to 11th March. The large difference between these two results may be attributable in part to the use of unscreened instruments in the present work, but pears in any event flower before apples.

Unfortunately, the extent to which the results of this experiment were influenced by a differential effect of the DNOC spray at the two sites cannot be ascertained, but it is thought to be small.

EXPERIMENT II, 1955.

Layout.

The object of the second experiment was to attempt to confirm the first year's results and to ascertain whether there was any " carry-over " effect of temperatures in one year to such an extent as to influence date of blossoming in the next. A subsidiary purpose was to determine whether the previous experiment had been started sufficiently early—i.e. whether spring temperatures prior to 11th March might influence date of flowering. These points were tested by interchanging some of the trees on 22nd January and 11th March 1955.

The Cox and Worcester trees in pots at site X were numbered 1 to 8 at random, and those at site Y, 9 to 16. The method of interchanging the trees is shown in Table III.

TABLE III.

Siting treatment of trees in pots, 1955.

Tree number	Siting during period P (11.3.54–22.1.55)	Siting during period Q (22.1.55–11.3.55)	Siting during period R (11.3.55–16.4.55)
1, 2	X	X	X
3, 4	X	X	Y
5, 6	X	Y	X
7, 8	X	Y	Y
9, 10	Y	X	X
11, 12	Y	X	Y
13, 14	Y	Y	X
15, 16	Y	Y	Y

As shown in Table III, three time periods were considered : (*a*) that between 11th March 1954 and 22nd January 1955, designated " P " (this period should have ended on 1st January, but snow delayed the interchange of the trees) ; (*b*) the period " Q " between 22nd January and 11th March 1955 ; and (*c*) the period " R " from 11th March to 16th April 1955.

During the winter one Worcester was blown over and broken off at the base, so that there were two " missing plots " in this variety. All the trees which had suffered from spray damage in the previous year appeared to have recovered, and use was therefore made of results from them.

The Cox trees which had been grown horizontally in 1954 were so severely damaged by scab and canker that no critical measurements could be made in this second year. However, three trees from each site were interchanged on 22nd January 1955 and their behaviour was noted.

The trees received no winter pruning beyond the removal of the small amount of damaged wood and they were not sprayed or manured. The sites were treated exactly as in 1954 and a further thick layer of straw was applied at site Y on 22nd January 1955.

Measurements.

In the light of the first year's results the methods of measurement were altered. Fewer assessments of bud growth were made and only 5 buds on each tree were considered. The method of selection was to count the total number (n) of fruit buds

on a tree and to label every n/5th bud, starting from the base. Terminal buds were not included, as the first year's observations suggested that they tended to behave atypically, being more advanced than lateral ones. The scoring system was altered slightly, points being assigned as follows :

breaking, 1 ; burst (leaves separating), 2 ; mouse ear, 3 ; green cluster, 4 ; early pink bud, 5 ; full pink bud, 6 ; king flower open, 7 ; full bloom, 8 ; petal fall, 9 ; fruitlet, 10.

Temperatures at each site were recorded by a thermograph at ground level, shielded from direct radiation by a bushel box standing on its side with its opening to the north. This method allowed a direct estimate of accumulated temperatures to be made, though at the expense of precision in the recording and interpretation of maximum and minimum temperatures.

Results.

Effect of siting upon the state of advancement of the fruit buds.

This was assessed on 16th April, 9th May, 13th May and 20th May 1955. There was less casual variation than in the first year, partly because no sprays were applied

Table IV.
Analysis of variance, Experiment II.

Source of variance	Degrees of freedom	Sums of squares	Variance	F	Significance (P)
Variety, V	1	87·8	87·8	10·33	N.S.
Error a	2	17·0	8·50		
Total a	3	104·8			
Date of assessment, D ..	3	23486·8	7828·9	7248·98	<0·001
D×V	3	250·3	83·4	77·22	<0·001
Error b	5	5·4	1·08		
Total b	14*	23847·3			
Period P	1	569·5	569·5	170·51	<0·001
Period Q	1	0·5	0·5	0·15	N.S.
Period R	1	242·0	242·0	72·46	<0·001
P×V	1	128·0	128·0	38·32	<0·001
Q×V	1	38·3	38·3	11·48	<0·01
R×V	1	22·8	22·8	6·83	<0·05
P×D	3	83·5	27·8	8·33	<0·001
Q×D	3	2·1	0·7	0·21	N.S.
R×D	3	6·0	2·0	0·60	N.S.
P×Q	1	0·1	0·1	0·03	N.S.
P×R	1	0·8	0·8	0·24	N.S.
Q×R	1	55·1	55·1	16·52	<0·001
P×Q×R	1	9·0	9·0	2·69	N.S.
Q×R×V	1	30·0	30·0	8·99	<0·01
Q×R×D	3	13·5	4·5	1·35	N.S.
Unnominated	34	119·4	3·5	1·05	N.S.
Error c	48	160·1	3·34		
Total	119†	25328·0			

* 15 less 1 " missing plot ".
† 127 less 8 " missing plots ".

and partly because of the method of scoring; therefore it was possible to analyse all the results together.

The figures for the total points (out of a possible fifty) scored by each tree on each date were analysed and the results expressed in terms of mean points scored per tree.

The main treatments were: variety (V), date of assessment (D) and the three spring periods (P, Q and R). The analysis was of the "split-plot" type and, to assist in interpreting the results, the analysis of variance is set out in Table IV.

Twenty-eight sources of variance due to treatments and their interactions could be considered in the lower part of Table IV, so that at least one of them might attain significance at $P = 0.05$ by chance alone. The system of nomination (Pearce, 1953) was therefore adopted and only those effects which the experiment was originally designed to test were considered. The combined unnominated interactions were non-significant.

The interaction of variety and date was significant ($P < 0.001$) and growth of flower buds on Worcester started later and proceeded more rapidly than on Cox. Fig. 3 shows that ten points scored corresponded to ten days' growth in Cox and eight days' growth in Worcester. The fact that the points lie close to a straight line in both instances suggests that the scoring system adopted was satisfactory.

The effect of period P, the spring treatment in the previous year, was large, and

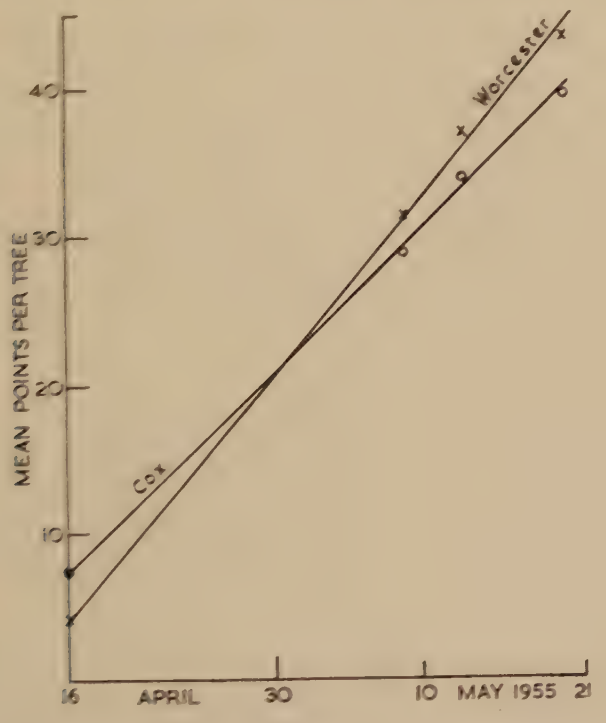

FIG. 3.

Fruit bud advancement in Cox and Worcester. Spring, 1955.

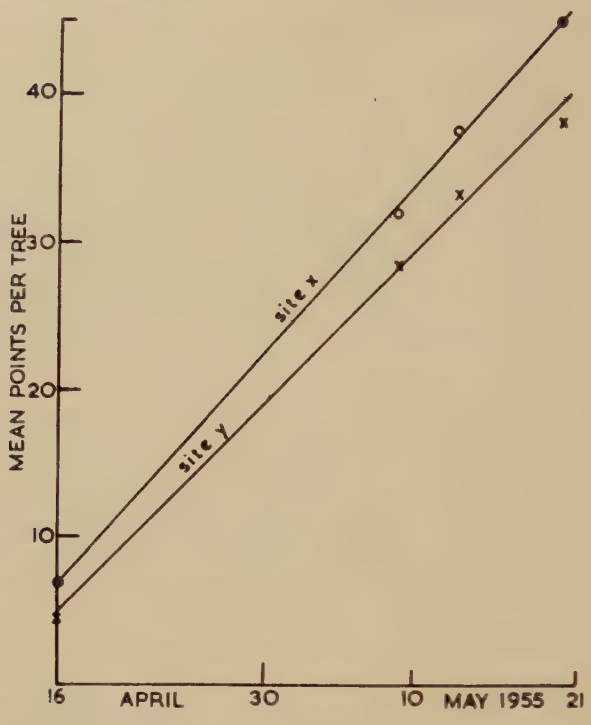

FIG. 4.
Effect of siting in 1954 upon fruit bud advancement at different dates in 1955.

this was confirmed by visual observation of the horizontal trees, which flowered although on M.II and only two years old. Cox was affected more than Worcester (Table V) and the effect actually became more marked as full bloom approached, although the time since application of the treatment was increasing (Fig. 4). These effects were all highly significant ($P<0.001$).

TABLE V.
Effect of siting in 1954 upon fruit bud advancement in 1955.

Variety	Site X (points)	Site Y (points)	Difference (days)
Cox	30·3	24·1	6
Worcester	30·0	27·8	2

L.S.D. ($P=0.05$), 0·9 points.

The effect of R, the siting treatment between 11th March and 16th April 1955, was significant ($P<0.001$) but smaller than that of P. It affected Cox significantly ($P<0.05$) more than Worcester (Table VI).

TABLE VI.

Effect of siting treatment between 11th March and 16th April 1955 upon fruit bud advancement in 1955.

Variety	Site X (points)	Site Y (points)	Difference (days)
Cox	29·0	25·4	4
Worcester	29·8	27·9	2

L.S.D. (P=0·05), 0·9 points.

The effect of R did not change with date of assessment (i.e. R×D was non-significant), although the temperature difference between the sites persisted after 16th April. This result could mean that the temperature treatment after this date had little effect on time of blossoming, a result consistent with Pearce and Preston's work (1954). However, other interpretations are possible and the point cannot be tested conclusively with the data from this experiment.

The effect of R was independent of P.

The period Q, which ran from 22nd January to 11th March, affected Cox in a different way from Worcester, and the second order interaction R×Q×V shows that this peculiar effect was confined to the trees which were moved from X to Y on 11th March (Table VII, italicized figure). These interactions were significant at P<0·01.

TABLE VII.

Effect of moving trees from X to Y on 11th March 1955 upon subsequent fruit bud advancement.

Siting after 11th March 1955	Cox formerly at site X (points)	Cox formerly at site Y (points)	Worcester formerly at site X (points)	Worcester formerly at site Y (points)
X	29·6	28·5	30·5	29·2
Y	*23·7*	27·2	28·3	27·6

L.S.D. (P=0·05), 1·3 points.

It appears that a period of higher night temperatures early in an otherwise cold spring has a marked delaying effect on Cox but no effect upon Worcester. This has some bearing on the first experiment. Before the final experiment began, all the trees were at an intermediate site, and the Cox trees which were placed at site Y on 11th March 1954 were probably set back by this move more than if they had spent the whole winter at site Y, where the Worcester trees were probably not influenced in this way.

Effect of siting on number of flower buds per tree.

In view of the considerable delay (10 to 12 days for Cox) brought about by siting the trees in a " frost pocket ", it seemed worth while to test whether the siting in one year had any detrimental effect on the number of flower buds per tree in the following spring. On 21st May 1955 a count of the total number of flower trusses

on every tree showed that siting in the previous year (i.e. period P) had in fact influenced the number significantly ($P<0{\cdot}05$). Both varieties were influenced in the same way, and the mean number of flower trusses on trees which had been sited at X in 1954 was 71·3, compared with 55·9 on those which had been at Y (L.S.D., 11·8 at $P=0{\cdot}05$).

Temperature records.

The number of day degrees accumulated above and below 42° F. could be calculated directly from the thermograph records. These began on 24th January 1955, but 11th March was taken as " zero day " for comparison with the results of the previous year (Fig. 5). As before, little difference was apparent between the numbers

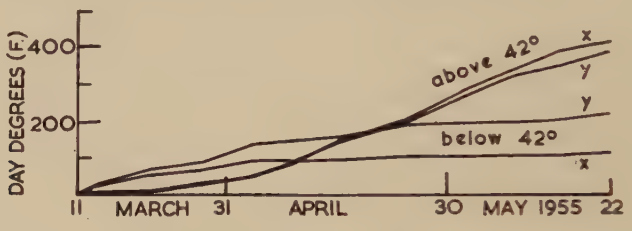

Fig. 5.

Accumulated temperatures at 4·5 in. above ground level, 1955.

of day degrees accumulated above 42° F. at the two sites, but there was a large difference between the numbers accumulated below this temperature. The difference was actually greater than indicated by Fig. 5 because temperatures below 18° F. could not be recorded, and such temperatures occurred more frequently at Y than at X.

Day maxima were likewise similar at the two sites but night minima differed widely. Fig. 6 shows the 7-day sliding mean minimum and maximum temperatures

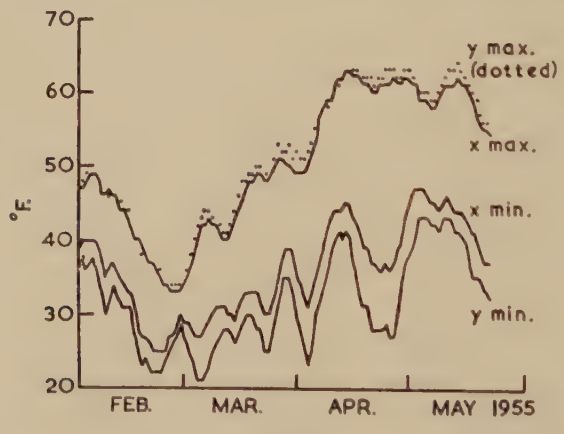

Fig. 6.

Sliding mean temperatures (7-day mean) at 4·5 in. above ground level, 1955.

PLATE I

Fig. 7.

(*a*) Vigorous growth in horizontal plane.

(*b*) Suppressed growth of the same tree in vertical plane.

For particulars, see text.

[*face p.* 254

and includes the period before 11th March. The total number of day degrees accumulated up to this date were : below 42° F., 305 at X and 350 at Y ; above 42° F., 26 at X and 33 at Y. It is remarkable that during so cold a spell the effect of siting on Cox was so marked.

The exact date of appearance of the first flowers was not noted, but it was about 9th May. Reference to Fig. 6 shows that on this date some 330 day degrees had been accumulated above 42° F. This compares with Herbst and Weger's figure of 253 for pears.

Fig. 7 illustrates an observation which, although it is not relevant to the body of this paper, seems worth recording. Those trees in Experiment I which were laid on their sides threw out branches more or less parallel to the ground. Shoots growing straight up or down remained very short. Fig. 7(a) is a photograph taken at 90° to the plane in which growth was most vigorous and Fig. 7(b) one taken parallel to this plane.

DISCUSSION.

The above results show that, although flowering of dwarf apple trees can be considerably delayed in a " frost pocket " where the cold is deliberately intensified (site Y), the amount of delay varies with different varieties and that trees which were at site Y in 1954 carried fewer flower buds in the following spring than those at site X for the same period. This latter result may have been influenced in some way by the amount of fruit carried by the trees (Table II), at least as regards those of Worcester Pearmain.

Many of the fruit buds, the opening of which was studied in 1954, were initiated on maiden wood during the summer of 1953 and might therefore be regarded as atypical ; but the results given by them do not differ materially from those obtained in the 1955 experiment.

No measurements of soil temperature were made, and while this in no way prejudices any conclusions reached about the effect of siting on the behaviour of the trees, it may be that soil temperature was more important than minimum air temperature in bringing about these effects. However, from the measurements that were made, it appears that, as Balchin and Pye found for other plants, night minimum temperature can be very important in determining the spring growth rate of both fruit buds and vegetative buds in the apple.

It also seems that, in the apple, Maclagan's " distal period " is very important in relation to date of flowering, a result already suggested by the statistical work of Pearce and Preston. These authors state that high June temperatures cause delay in the following season but, although the present work supports this view, the temperature differences in this month were small (Table VIII) and hardly seem sufficient by themselves to have caused the large observed differences in flowering dates.

These results with apples do not agree closely with the view of Herbst and Weger that the spring growth of flower buds in the pear follows closely the accumulated temperatures above 42·8° F. The results suggest that, for the apple, a certain minimum number of day degrees above 42° F. must be received by the tree in the spring before it can flower, but that, after this minimum requirement has been fulfilled, the date of flowering will depend upon the nocturnal temperatures and upon the temperature treatment received in the previous year. This hypothesis is consistent with

TABLE VIII.

Accumulated temperatures at 4·5 in. above ground level, in June 1954 (exposed thermometers).

Period (June)	Day degrees			
	Above 42° F.		Below 42° F.	
	At X	At Y	At X	At Y
1–15 ..	259	259	0	11
16–30 ..	325	335	1	12

Pearce and Preston's conclusion that the number of day degrees accumulated above 42° F. after about the middle of April normally has little influence upon date of flowering.

SUMMARY.

1. Microclimatic differences between sites having high (site X) and low (site Y) night temperatures were sufficient to cause delay in the spring growth of both vegetative and flower buds of dwarf apple trees at site Y. After flowering, however, the trees at this site became the more advanced in vegetative growth for a short period, but the difference subsequently disappeared.

2. By interchanging the trees between the two sites it was found that the difference in date of flowering appeared to relate as closely to the temperature treatment during the previous growing season as to the spring temperatures in the current year. Thus the delay was more marked in the second year spent at site Y than in the first.

3. In the spring, night minimum temperatures and accumulated temperatures below 42° F. appeared to be more important in determining the date of flowering than day maxima or accumulated temperatures above 42° F. The latter differed little from site to site.

4. Trees of Cox's Orange Pippin which spent the early part of the spring at site X and were subsequently moved to site Y on 11th March were more delayed than trees which spent the entire spring at the "cold" site Y. Trees of Worcester Pearmain were not affected by such treatment.

5. The response to these microclimatic temperature differences was generally more marked in Cox's Orange Pippin than in Worcester Pearmain. The delay in flowering of the former variety at site Y amounted to 10–12 days in 1955.

6. Spring growth of flower buds in Worcester Pearmain started later and proceeded more rapidly than in Cox's Orange Pippin.

7. Siting trees at Y in one year appeared to decrease the number of flower buds carried in the following spring.

ACKNOWLEDGMENTS.

Thanks are due to Professor R. H. Stoughton for advice throughout the work, and to the Ministry of Agriculture, Fisheries and Food for the post-graduate scholarship during the tenure of which this work was carried out.

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AN EXAMINATION OF FACTORS CONTRIBUTING TO THE pH OF THE JOHN INNES COMPOSTS

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THE physical and chemical standardization of the John Innes pot plant composts, within the limitations imposed by each component material, has given relatively uniform and reproducible standards of plant growth. The composts were formulated empirically and, whilst abundant evidence exists on growth and cropping, no data are available as to their physical and chemical characteristics. This paper presents the results of a study of the principal factors contributing to changes in the hydrogen-ion concentration of the composts under normal glasshouse management.

Several workers, including Arnon and Johnson (1942), have demonstrated that, where suitable measures are taken to maintain the availability of nutrients, higher plants are able to grow in culture solutions over a pH range of 4·0 to 8·0 before hydrogen-ion concentration *per se* affects growth. In soils, however, pH 6·0–6·5 is accepted as giving the maximum availability of macro-nutrients, so that pH control is desirable. Maintaining the pH at this level also avoids the possibility of phytotoxicity induced by excess soluble manganese, a condition made more liable by steam-sterilizing the loam. Observation has shown that, although all materials are standardized, the pH of the composts shows wide fluctuations, considerably greater than the normal periodic variation found in soils.

MATERIALS AND METHODS.

The composts consisted of 58·3 per cent. steam sterilized loam, 25 per cent. peat and 16·7 per cent. grit, all measured by volume. John Innes base fertilizer (organic N, 5·1 per cent. ; soluble P_2O_5, 7·2 per cent. ; K_2O, 9·7 per cent.) was added at the rate of 3·1 gm. per litre, together with 0·6 gm. of ground limestone.

Three loams were used in the experiments : A, a brick-earth, pH 6·5 ; B, a chalky boulder clay with 3–5 per cent. free $CaCO_3$, pH 7·5 ; C, a light gravel loam, pH 5·1. Two peats (*a*) Irish sphagnum moss, pH 3·9, and (*b*) Somerset sedge, pH 4·4 ; and two grits (*a*) granite, and (*b*) limestone chips, were used. The peat particles graded up to $\frac{3}{8}$ in. in diameter and the grits to $\frac{1}{8}$ in. The limestone grit had 93 per cent. by weight of particles in the range $\frac{1}{16}$–$\frac{1}{8}$ in.

Hydrogen-ion concentration of the soil suspension was determined with a glass electrode, a soil/water ratio of 1 2·5 being used unless otherwise stated. The hydrolysis effect obtained by varying the soil water ratio is well known (McGeorge, 1938) and is illustrated by the results given in Table I. These show that the customary 1/2·5 ratio gives values of up to 0·3 units higher than those obtained from either a soil paste or a suspension of soil in a weak electrolyte such as 0·01 M $CaCl_2$, as used by Schofield and Wormald Taylor (1955).

Ammoniacal and nitrate nitrogen were extracted by shaking for two minutes in Morgan's solution (0·73 N sodium acetate, 0·52 N acetic acid) and determined colorimetrically by the method of Peech and English (1944). A soil solvent ratio of 1/3 on a volume basis was chosen in preference to the more usual 1 5 ratio on a

Table I.

Hydrolysis effect of soil/water ratio on pH.

Soil type	Soil/water ratio					Suspension with 0·01 M $CaCl_2$ (1/2·5 ratio)
	Paste	1/1	1/2·5	1/5	1/10	
J.I. Compost No. 1 (50 p.p.m. NH_3-N)	5·9	5·9	6·2	6·3	6·4	5·9
J.I. Compost No. 1 (64 p.p.m. NO_3-N)	4·4	4·4	4·6	4·7	4·9	4·4
Loam B (3–5% $CaCO_3$)	7·3	7·4	7·5	7·7	8·0	7·3

weight/volume basis. The volume basis would appear to be more suitable for sampling and for expressing results, especially in pot work.

The composts were well mixed to minimize chemical and physical variations and the following mean values with standard errors were found :

pH sample : mean, 7·02 ; S.E., ± 0·025 ; 6 d.f.
Ammonia sample : mean, 100·5 p.p.m. ; S.E., ±2·3 ; 6 d.f.
Nitrate sample : mean, 15·3 p.p.m. ; S.E. ±0·83 ; 6 d.f.

The buffer capacities of the various materials and of a compost were determined by plotting pH changes against increments of 0·05 N $Ca(OH)_2$ and 0·05 N H_2SO_4 (Fig. 1). In addition to showing the buffering against alkalinity and acidity, the lime

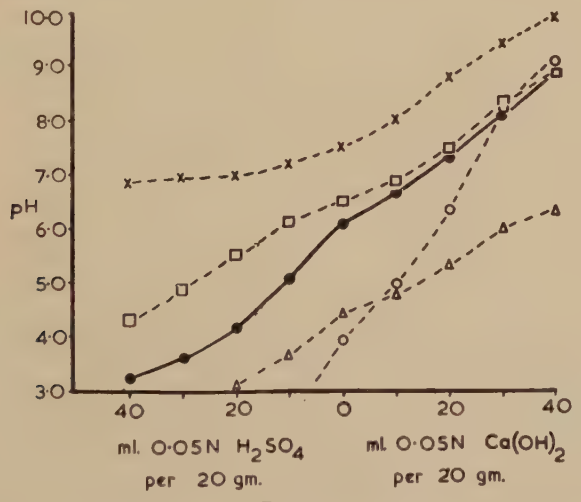

Fig. 1.

Buffer capacities of certain materials and of a compost made from loam A, moss peat and granite grit.

Loam A, □ ; loam B, × ; sphagnum moss peat, ○ ; sedge peat, △ ; compost, ●.

and sulphur requirements for any desired pH change can be estimated. The factors which determine the rate of sulphur oxidation and the consequent interval to effect a reduction in pH are examined below (Table VIII).

The composts studied in this work had either been stored in bulk for periods of up to twelve weeks or had been freshly prepared. It will be convenient to describe the results under the corresponding headings.

Stored composts.

The principal difference between the composts and ordinary soils is that the loam used in the former is normally first partially sterilized by heat before the addition of the peat, grit and fertilizers. Determinations on a number of soils immediately before and after sterilization had shown that any purely chemical changes induced by sterilization were insufficient to cause a significant change in pH. On storage, however, the pH of the compost made with sterilized loam rose 0·6 units with a subsequent fall to 1·0 unit below the original value (Fig. 2). With compost made from unsterilized loam, a progressive fall in pH of 1·0 unit occurred.

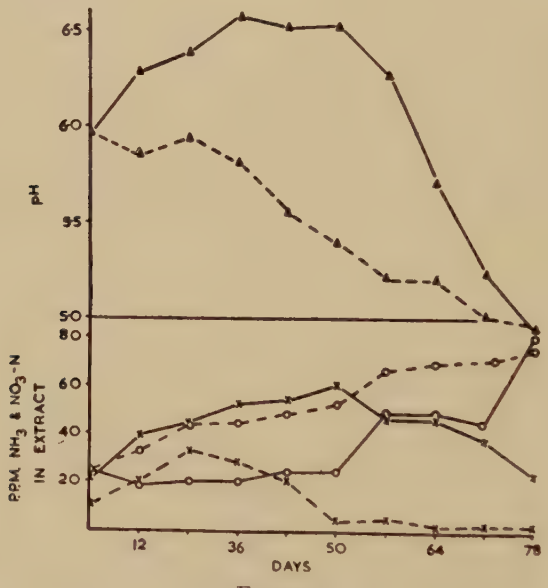

Fig. 2.

Ammonia and nitrate concentration in composts made from sterilized and unsterilized loams in relation to pH.
pH, △ ; NO_3-N, ○ ; NH_3-N, ×.
Sterilized compost, ——— ; unsterilized compost, – – – –.

Of the many chemical and biological changes induced by sterilization, ammonification and subsequent nitrification, which result from the biological breakdown of organic nitrogen, are the most probable causes of the observed changes in pH. It should follow, therefore, that any conditions which influenced the intensity of

biological activity would also affect the degree and speed of pH change. The factors considered most likely to have a contributory effect were temperature, moisture, soil reaction, contamination following sterilization and amount of nitrifiable organic matter present. The influence of these separate factors on the rates of ammonification and nitrification under practical conditions was studied. In the following experiments composts were made from loam A, sphagnum moss peat and granite grit, unless otherwise stated.

Temperature.

Three temperature ranges, 3°–6° C., 11°–15° C. and 18°–25° C., were used (Fig. 3). With the 3°–6° C. range, both pH and ammoniacal nitrogen showed a gradual increase over nine weeks. There was no indication that the maximum value of either

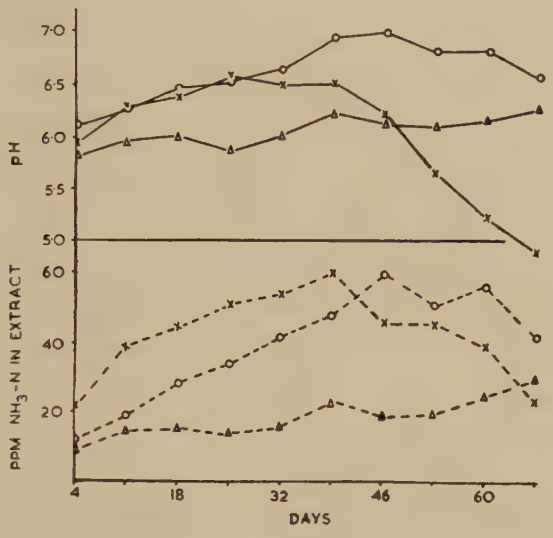

Fig. 3.

pH and ammonia curves in sterilized composts stored at three temperatures.
3°-6° C., △ ; 11°-15° C., ○ ; 18°-25° C., ×.
pH, ——— ; NH_3-N, – – – –.

had been attained. No nitrification was observed. At 11°–15° C., the pH had increased by 0·8 unit and ammonification reached a peak of 60 p.p.m. in the extract at the sixth week. Nitrification began after this point and increased gradually. At 18°–25° C., ammonification and nitrification were completed by the ninth week. The slow rates of ammonification and nitrification at low temperatures are similar to those reported by Davies and Owen (1953) for glasshouse soils *in situ*.

Moisture.

For ease of handling and economy in steam, the moisture content of a medium clay loam should not exceed 25–30 per cent. of the oven-dry weight. In composts

the moisture content is reduced to 15–20 per cent., this being referred to as " potting condition ". The effect of allowing the moisture content of compost prepared from sterilized loam to fall to air-dry level (5 per cent.), with subsequent readjusting to potting condition (17 per cent.), is shown in Table II. While the compost was in the

TABLE II.

Effect on pH and NH_3-N of readjusting the moisture level to " potting condition " after compost has been in the air-dry state for 13 days and 32 days.

Days after sterilizing and mixing	Control compost with 17% moisture continuously		Air-dried compost re-wetted to 17% moisture content			
			After 13 days		After 32 days	
	pH	NH_3-N	pH	NH_3-N	pH	NH_3-N
4	6·2	10				
11	6·4	23	6·2	12		
18	6·6	30	6·5	18		
25	6·7	36	6·6	32		
32	6·8	46	6·7	35	6·2	9
39	7·0	42	6·7	38	6·5	26
46	6·8	44	6·8	44	6·7	31
53	6·7	57	6·8	54	6·8	40
60	6·5	38	6·7	46	6·7	43
67	6·3	35	6·6	40	6·7	50

air-dry state, ammonification was arrested but it was resumed when the moisture level was restored. The stimulus received from sterilization was still evident after 32 days in the air-dry state, during which time the compost had been exposed to aerial contamination.

With a temperature range of 11° to 15° C., increasing the moisture level from 17 to 23 per cent. (the maximum moisture content at which the compost could be conveniently handled for potting) was without effect. No differences were found as the result of increasing the moisture content within practical limits either before or after sterilizing, provided the same moisture levels were reached.

Soil reaction.

Walker and Thompson (1949) found that increasing amounts of calcium hydroxide added before sterilizing resulted in increased ammonification. It can be reasoned that, if the rate of ammonia production after sterilizing is primarily dependent on biological activity rather than on purely chemical changes resulting from thermal effects, and if the principal function of the calcium hydroxide in relation to ammonification is to provide a more favourable degree of soil reaction for biological activity, then the time of its application, i.e. before or after sterilization, should produce the same effect. To test this point, loam C, the light gravel with a pH of 5·1, was chosen. The pH and ammonia changes, with calcium hydroxide applied before or after sterilizing, and those of a control without it are given in Table III. The time of application of calcium hydroxide is shown to be immaterial. Furthermore, the rate of ammonification in both treatments is considerably greater than in the control, which has a high hydrogen-ion concentration. The same response was

Table III.

Addition of $Ca(OH)_2$ at 3·3 gm./litre to an acid loam before or after steam sterilizing, as affecting pH and ammonification.

Days after sterilizing	Acid loam No $Ca(OH)_2$		$Ca(OH)_2$ before sterilizing		$Ca(OH)_2$ after sterilizing	
	pH	NH_3-N	pH	NH_3-N	pH	NH_3-N
4	5·1	14	7·2	16	7·2	16
11	5·3	12	7·4	27	7·4	30
18	5·2	15	7·4	34	7·4	35
25	5·3	15	7·5	39	7·6	37
32	5·5	19	7·7	34	7·8	35
39	5·6	22	7·6	42	7·6	42
46	5·5	23	7·6	44	7·6	45
53	5·6	27	7·5	46	7·5	44
60	5·7	27	7·5	40	7·5	48
67	5·6	32	7·2	38	7·5	46

obtained when the base fertilizer supplying N, P_2O_5 and K_2O was added to all treatments.

The choice of loam and grit, by modifying the hydrogen-ion concentration of the compost, also affects the interval between sterilization and nitrification. Composts having either loam B (chalky boulder clay with 3–5 per cent. free carbonate and pH 7·5), or limestone in place of the granite grit, showed more rapid nitrification than a control compost having no free carbonates (Fig. 4). The high ant-acid buffer capacity

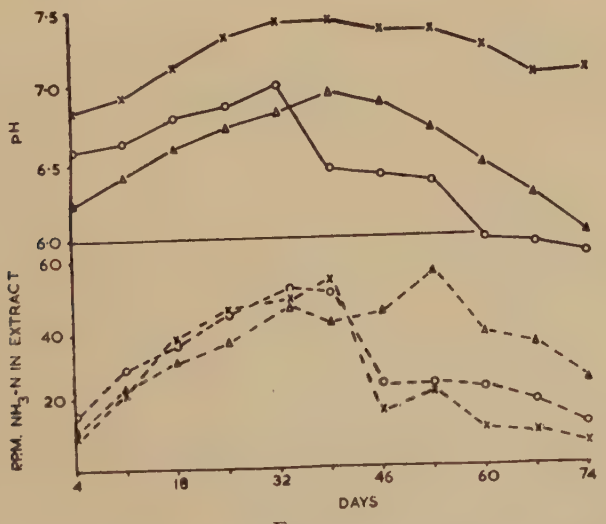

Fig. 4.

Composts made from boulder clay loam and limestone grit showing more rapid mineralization of nitrogen than the standard control compost.

Composts : control, △ ; boulder clay, ○ ; limestone grit, ×.
pH, ——— ; NH_3-N, – – – –.

of the limestone grit prevented the fall in pH usually associated with nitrate accumulation.

Contamination.

Normally only the loam is steam-sterilized and the addition of unsterilized peat and grit, together with the mixing of the materials in either a sterilizing or a potting shed, affords ample opportunity for subsequent reinoculation with nitrifying and other organisms. Russell and Hutchinson (1909) and subsequent workers have shown that nitrification in freshly sterilized soils is inhibited for a period.

The effects of deliberate gross contamination, over and above that already described, were observed by making a compost from 86 per cent. sterilized and 14 per cent. unsterilized loam. A compost was also made from loam which had been sterilized and stored in open bins for six weeks prior to mixing. The effect of these practices on the pH and ammonia changes are shown in Fig. 5. The inclusion of a

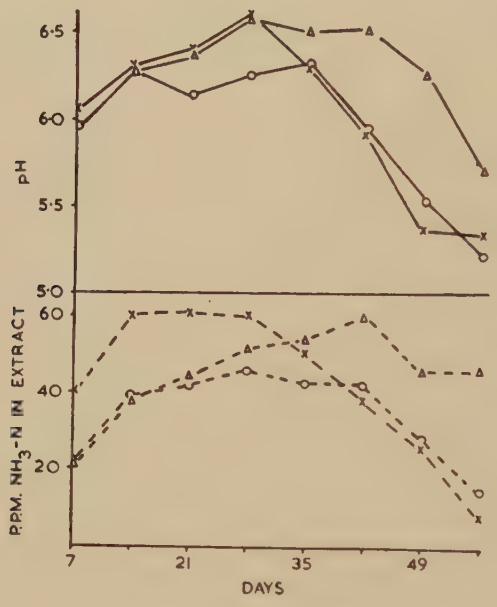

FIG. 5.

Effect of adding unsterilized to sterilized loam and also of storing sterilized loam for six weeks before making into compost.

Composts : control, △ ; from sterilized + unsterilized loam, ○ ; from loam stored six weeks, ×. pH, ——— ; NH_3-N, – – – –.

quantity of unsterilized loam resulted in lower pH and ammonia values as compared with the standard compost, whereas they rose more rapidly with compost made from stored sterilized loam. With both of these modified composts nitrification commenced sooner than in the control.

Nitrifiable organic matter.

The ammonia content of composts which have been sterilized is produced partly by the breakdown of organic matter in the loam and partly from the added organic nitrogenous fertilizer. To accommodate the varying vigour of pot plants it is customary to double or treble the quantity of base fertilizer added. The composts are then described as John Innes potting composts No. 1, No. 2 and No. 3. These increases in base fertilizer, which contains 5·1 per cent. organic nitrogen, result in increased pH and ammonia values (Table IV). The composts were made from

Table IV.

Increase in pH and NH_3-N on storing John Innes composts having three rates of base fertilizer (J.I. No. 1, No. 2 and No. 3).

Days after sterilizing and mixing	Compost No. 1		Compost No. 2		Compost No. 3	
	pH	NH_3-N	pH	NH_3-N	pH	NH_3-N
4	6·2	11	6·2	13	6·1	18
11	6·2	19	6·4	28	6·4	42
18	6·5	28	6·5	40	6·7	56
25	6·6	34	6·7	54	6·9	72
32	6·7	42	6·8	65	7·0	86
39	7·0	48	7·0	80	7·2	110
46	7·0	60	7·1	96	7·2	114
53	6·8	52	7·0	88	7·1	115
60	6·8	57	7·0	84	7·1	111
67	6·8	36	7·0	90	7·0	95

loam A which has 2·5 per cent. organic carbon (Walkley and Black value). Each increment of fertilizer increased the concentration of ammonia in the extract by approximately 30 p.p.m. The ammonia values given in Table IV are those found in the acetic acid-sodium acetate solvent and do not give the total concentrations in the composts.

Immediately used composts.

When composts made from fresh steam-sterilized loam were used for growing plants in pots on the glasshouse bench, the pH and ammonia curves deviated in several ways from those of similar composts in storage. The rise in pH was very rapid, maximum values being reached after two weeks (Fig. 6). Ammonification and nitrification were also more rapid, being completed within four weeks in pots containing tomato seedlings and within six weeks in pots without seedlings on the glasshouse bench. This effect can be attributed to the more favourable conditions previously described, namely, temperature, moisture and contamination. The diurnal and day-to-day temperature range in the pots was 17°–32° C. and, as in normal glasshouse management, the water content fluctuated around field capacity level.

The interaction and relative importance of these factors on the rates of ammonification, nitrification and pH change were studied in a factorial experiment with two temperature ranges, 10°–14° C. and 20°–23° C., and with two moisture levels, 25 and

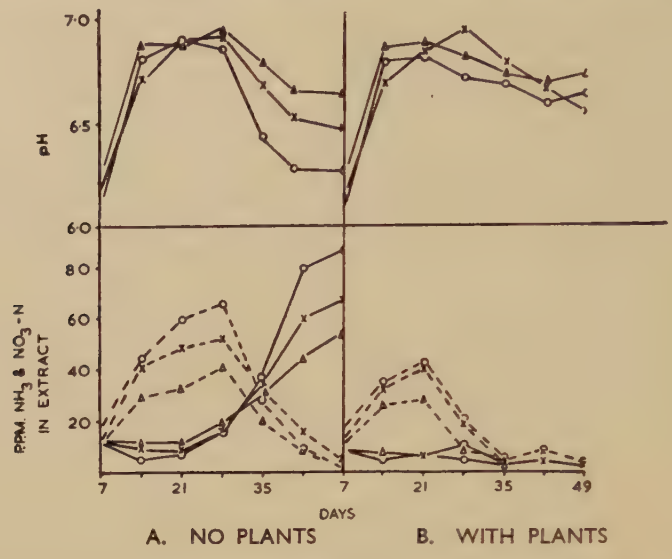

FIG. 6.
pH, ammonia and nitrate changes in composts of three fertilizer strengths, with or without plants under glasshouse conditions.

Above : pH, ———. *Below :* NO_3-N, ——— ; NH_3-N, – – – –.
Composts : No. 1, △ ; No. 2, × ; No. 3, ○.

41 per cent. of oven-dry weight ; in addition, the standard " sterile " compost was compared with one containing 98 per cent. of freshly sterilized and 2 per cent. of unsterilized loam. The results are presented in Table V. Ammonia and nitrate values were determined weekly and, as before, were found to be closely correlated with pH. The conditions normally found in pots, viz. relatively high temperatures and moisture levels and a certain degree of contamination by way of soil remaining on the seedlings' roots, are shown to give more rapid mineralization of nitrogen with its consequent effect on pH.

The appreciably lower ammonia concentration in composts with growing plants (cf. Fig. 6B with 6A) was primarily due to absorption by the plants and to some additional loss by leaching. Examination of the leachate from the pots showed that its ammonia content ran parallel to that of the composts. Mean values of ammoniacal nitrogen in 200 ml. of leachate, collected from nine plants in each treatment, showed a maximum concentration in the second week of 25 p.p.m. with John Innes compost No. 1, 45 p.p.m. with compost No. 2 and 80 p.p.m. with compost No. 3. The water-soluble ammoniacal nitrogen content of the compost was found to be high, being approximately 80 per cent. of that extracted by the acetic acid-sodium acetate solvent.

With composts made from unsterilized loam, the pH was more stable, the slight rise which occurred after the first week being the result of ammonification temporarily exceeding nitrification and absorption by the plant.

Table V.

Rate of pH change in the John Innes compost No. 1 after sterilization, as affected by the environment.

Days after sterilizing and mixing	Hot,† wet, inoculated	Cold, wet, inoculated	Hot, wet, "sterile" ‡	Hot, dry, inoculated	Hot, dry, "sterile"	Cold, dry, inoculated	Cold, wet, "sterile"	Cold, dry, "sterile"
4	5·6	5·5	5·6	5·5	5·5	5·4	5·4	5·3
11	5·8	5·6	5·9	5·8	5·8	5·8	5·6	5·5
18	[5·9]*	5·8	6·0	6·0	5·9	5·7	5·8	5·7
25	5·7	[5·9]	6·1	6·0	6·0	5·7	5·8	5·6
32	5·3	5·7	6·0	6·0	6·2	5·7	5·8	5·6
39	5·0	5·8	[6·1]	[6·1]	6·1	5·9	5·9	5·9
46	4·7	5·5	6·0	5·9	6·1	5·8	6·0	5·8
53	4·5	5·4	5·9	5·8	6·2	5·9	6·0	6·0
60	4·5	5·3	5·6	5·8	[6·1]	5·9	5·9	6·0
67	4·5	5·0	5·2	5·7	5·9	5·8	5·9	5·9

* Figures in brackets show commencement of nitrification.
† Hot, 20–23° C. ; cold, 10–14° C. ; dry, 25% moisture ; wet, 41% moisture.
‡ " Sterile ", standard compost.

Long period changes in composts.

The hydrogen-ion changes so far discussed take place within a short period, normally four to six weeks. The principal factors contributing to a change after this period were found to be the quality of the irrigation water and the quantity and type of fertilizer used in the preparation of the composts and for supplementary feeding. The effect of the quality of the irrigation water on the compost pH has been studied by the use of (*a*) static water, collected from the glasshouse roofs and having a total alkalinity equivalent to 62 p.p.m. $CaCO_3$, (*b*) mains water, with a total alkalinity equivalent to 258 p.p.m. $CaCO_3$. An experiment including four base fertilizer and two water treatments showed that the continued use of either mains or static water for twelve weeks resulted in a pH gradation in the pot (Table VI). Samples taken from the upper 3 cm. layer gave an increase over those from the lower 3 cm. layer of 0·5–0·8 pH units with the static water and 1·5–2·4 with the mains water. Vertical samples have been taken as giving the mean pH of the treatment. All treatments received one application of the John Innes liquid fertilizer at 6 gm. per litre. The acidifying action of this single application was insufficient to prevent a pH rise in the mains water treatment of from 1·0 to 1·4 units.

In formulating the composts, calcium carbonate was included partly to neutralize the acidifying effects of the fertilizer and partly to assist in overcoming the check to seedling growth frequently resulting from the heat sterilization of soils. Unless the quantity of calcium carbonate added balances precisely the acidity developed by the fertilizer, the ultimate pH of the compost can be expected to vary with the fertilizer concentration of the compost used, as given by John Innes compost No. 1, No. 2 or No. 3. The effect of different strengths and combinations of base fertilizer and calcium carbonate on the final pH after growing tomatoes is shown in Table VI. The major differences, due to fertilizers, irrigation water and the gradients within the pots are statistically significant ($P<0·001$).

TABLE VI.

pH changes arising from different rates of base fertilizer and from the quality of the irrigation water (after 12 weeks' growth of tomato plants).

Irrigation water	Fertilizer rate							
	1 Ca, 1 F*		3 Ca, 3 F		1 Ca, 3 F		3 Ca, 1 F	
	Upper 3 cm.	Lower 3 cm.	Upper 3 cm.	Lower 3 cm.	Upper 3 cm.	Lower 3 cm.	Upper 3 cm.	Lower 3 cm.
Static (62 p.p.m. $CaCO_3$)	5·6	4·9	5·8	5·2	5·5	4·7	6·1	5·6
Difference	0·7		0·6		0·8		0·5	
Vertical core sample	5·2		5·3		5·0		5·7	
Mains (258 p.p.m. $CaCO_3$)	7·4	5·6	7·4	5·8	7·4	5·0	7·6	6·1
Difference	1·8		1·6		2·4		1·5	
Vertical core sample	6·7		7·0		6·5		7·3	

* 1 Ca, 1 F : calcium carbonate and fertilizer constituents as in J.I. compost, No. 1.
S.E. of pH data, ±0·314 (120 d.f.).

The total acidity of the fertilizers commonly used in pot plant growing has been assessed on the method of Pierre (1933). By this method total acidity includes an allowance for 50 per cent. of the nitrogen being acid-forming and the result is expressed as acidity equivalent to pounds of calcium carbonate per 2,000 lb. of fertilizer. The following data were obtained :

Fertilizer	Total acidity
J.I. base fertilizer	168
J.I. liquid fertilizer	1,967
Ammonium sulphate	2,178

The J.I. liquid fertilizer has an approximate analysis of N 18·6, P_2O_5 6·2, K_2O 6·2 per cent. by weight. The effects of six weekly applications of this fertilizer at 3 and 6 gm. per litre (approximately 0·5 and 1·0 oz. per gallon respectively), on composts having different ant-acid buffer capacities and watered with either static or mains water, are given in Table VII. The ant-acid buffer capacity of the compost was increased by including a quantity of limestone in place of the granite grit.

Weekly supplementary feeding with 6 gm. per litre caused a reduction in pH over the controls of 2·7 units with the mains water and 1·6 units with the static water. The replacement of 25 per cent. of the granite with limestone grit prevented the final pH from falling below 6·0 and also resulted in a reversal of the normal pH gradient, i.e. the top 3 cm. layer then had a lower pH value than the base layer. The major differences, due to fertilizers, irrigation water and composts, are statistically significant ($P<0·001$).

USE OF SULPHUR.

The relatively high pH values make the John Innes composts unsuitable for growing certain calcifuge plants, in particular *Ericaceae*. To overcome this, the calcium carbonate normally included in the mixing of the composts has been replaced

TABLE VII.

Depression in pH of normal and limestone-buffered composts from six weekly supplementary fertilizer applications.

Compost with :		Fertilizer					
		Nil		3 gm./litre		6 gm./litre	
Granite	Limestone	Mains	Static	Mains	Static	Mains	Static
Control 100%	0%	7·3 (+1·1)*	5·5 (+0·9)	5·6 (+0·9)	4·4 (−0·3)	4·6 (+0·9)	3·9 (−0·1)
90%	10%	7·3 (+1·0)	7·0 (+0·1)	6·6 (+0·1)	5·9 (−0·8)	5·8 (−0·1)	4·9 (−0·8)
75%	25%	7·8 (+0·4)	7·4 (+0·2)	7·0 (−0·4)	6·5 (−1·2)	6·4 (−0·5)	6·1 (−1·2)

* pH gradients ; +, higher value in top 3 cm. layer than lower ; −, conversely.
S.E. of pH data (excluding those in brackets), ±0·216 (51 d.f.).

with sulphur (Alvey, 1955). The thermal death point of the non-spore-forming sulphur oxidizing *Thiobacillus* is 60° C. and to determine whether, in common with the nitrifying organisms, there is a period of inhibition of the *Thiobacillus* following sterilization, sulphur was included in composts made from steam-sterilized loam and stored in different environments. A compost having sulphur but made from unsterilized loam was included as a control. The rate of pH change was taken as a measure of the rate of sulphur oxidation. Table VIII shows that high temperature

TABLE VIII.

Rate of sulphur oxidation as measured by pH in unsterilized and sterilized composts in different environments.

Days after sterilizing and mixing	Un-sterilized compost	Sterilized composts							
	Hot,* wet	Hot, wet, inocu-lated†	Hot, wet, " ster-ile "‡	Hot, dry, " ster-ile "	Hot, dry, inocu-lated	Cold, wet, inocu-lated	Cold, wet, " ster-ile "	Cold, dry, inocu-lated	Cold, dry, " ster-ile "
4	5·3	5·1	5·1	5·0	5·0	4·9	5·0	4·8	4·8
11	5·1	5·2	5·3	5·1	5·2	5·2	5·2	5·3	5·0
18	5·0	5·0	5·4	5·0	5·1	5·2	5·1	5·1	5·0
25	4·7	4·7	4·9	5·0	4·8	5·2	5·3	5·1	5·1
32	4·6	4·5	4·5	4·5	4·7	5·1	5·1	5·1	5·1
39	4·4	4·4	4·3	4·7	4·6	5·1	5·0	5·2	5·1
46	4·4	4·3	4·3	4·6	4·6	4·9	5·0	5·1	5·1
53	4·1	4·3	4·2	4·5	4·6	4·7	4·8	5·1	5·0
60	4·2	4·3	4·3	4·4	4·5	4·6	4·7	5·1	5·1
67	4·2	4·2	4·2	4·4	4·5	4·5	4·6	4·9	5·1

* Hot, 20–23° C. ; cold, 10–14° C. ; dry, 25% moisture ; wet, 41% moisture.
† 2% by volume unsterilized loam used in making the standard compost.
‡ " Sterile ", standard compost.

and moisture favour sulphur oxidation. Deliberate re-inoculation with 2 per cent. by volume of unsterilized loam did not materially increase the oxidation rate over the non-inoculated treatments. Under conditions of high temperature and moisture the rate of oxidation was comparable in sterilized and unsterilized composts, maximum pH reduction occurring within nine weeks. Determinations of ammonia and nitrate nitrogen made throughout the experiment showed an accumulation of ammonia but nitrification was inhibited in all treatments. During the course of the experiment a small reduction in the original nitrate concentration was observed.

Hydrangea, grown in composts in which sulphur was used as a means of reducing the pH and assisting in the production of blue flowers, showed a marked interveinal leaf chlorosis for several weeks after potting-up.

DISCUSSION.

The data show that, although the John Innes composts are made to standard formulae, they show wide differences in hydrogen-ion concentration after they are prepared. These are the result of successive changes in the concentration of ammonium and nitrate ions. The differences in pH are large in comparison with the periodic variations found in agricultural soils and are caused by the large amount of fertilizer used ; the concentration of organic nitrogenous fertilizer in the No. 1 compost is equivalent to 14·5 cwt. of hoof and horn (13 per cent. N) per acre per six inch depth.

Partial sterilization stimulates the biological production of ammonia and this causes a pH rise of up to 0·6 unit, and subsequent nitrification results in a pH depression of about 1·0 unit below the original value. When the composts are stored in winter the limiting factor controlling the rate of change is low temperature, whereas in summer it is low moisture content.

The maximum rate of mineralization of nitrogen occurs with a soil temperature of about 35° C., a moisture content of 80 per cent. of the soil capacity and a soil reaction of 6·8–7·5 (Waksman, 1952 ; Shaw, 1952). These optimum temperature and moisture conditions are closely approached when the compost is in pots in the glasshouse ; hence the rate of pH change is quicker than when the compost is stored. Increasing the content of base fertilizer increases the pH range but does not extend the period of conversion to mineral nitrogen.

The hydrogen-ion concentration of the compost in a pot, after mineralization and absorption of the nitrogen, is seldom either stable or uniform. Stratification in pH can result either from supplementary feeding or from the retention in the upper compost layers of the bicarbonates present in the irrigation water. Micro-sampling of a single horizon in the pot has shown that differences of 0·5 unit between the peat and loam particles can still be detected after six months. Differences in pH within the pot may be as large as 2·4 units (Table VI) and this precludes any attempt at correlating plant response with pH as determined purely from a vertical core sample.

The addition of sulphur in large quantities to pot plant composts immediately prior to using, in order to effect a pH reduction, is not desirable. Sulphur has been found to inhibit nitrification and also to show a tendency towards promoting denitrification. This lack of nitrification in sulphur-treated soils is in agreement with the results of Cornfield (1953) and Massey (1952). It is attributed by Waksman (1952) to the production of intermediate products in the oxidation of the sulphur, principally hyposulphites, which are toxic to plants or inhibit nitrification.

SUMMARY.

The principal factors influencing the hydrogen-ion concentration of the John Innes composts have been assessed. Mineralization of the organic nitrogen results in wide fluctuations in pH. Biological activity, which determines the rates of ammonia and nitrate production, is influenced by temperature, moisture, soil reaction and re-inoculation following steam-sterilization. Maximum mineralization of nitrogen can occur within six weeks in pots on glasshouse benches.

Subsequent pH changes are primarily dependent on the quality of the irrigation water and the quantity and type of supplementary fertilizer, either of which may cause a pH gradation within the pot.

Increasing the ant-acid buffer capacity of the compost by the use of limestone grit reduces the fall in pH normally resulting from supplementary fertilizers.

The rate of sulphur oxidation and of consequent pH reduction in composts to which sulphur has been added is primarily dependent on temperature and moisture content.

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BITTER ROT OF APPLES

II. SEASONAL VARIATIONS IN THE DEVELOPMENT AND SPORULATION OF CANKERS OF *GLOEOSPORIUM* SPP. INOCULATED INTO APPLE BRANCHES

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THE bitter rot fungi have caused increasing losses in stored Cox's Orange Pippin apples during recent years. The species mainly responsible are *Gloeosporium perennans* Zeller and Childs and, to a lesser degree, *G. album* Osterw. In 1924 Kidd and Beaumont (5) reported *G. album* on fruit in Britain and Ogilvie (8) subsequently noted its increasingly common occurrence as a saprophyte on pruning snags of apple. *G. perennans* was first reported in Britain by Wilkinson in 1943 as occurring on apple branches and fruit, especially where pruning was done during the summer instead of during the winter (11, 13, 14, 15).

Preliminary results obtained at Long Ashton in 1953–54 on the shoot infection phase of *Gloeosporium perennans* and *G. album* were given in a previous paper (3). These results, based mainly on the records obtained during the first three months after inoculation, have been generally confirmed by further records obtained during the ensuing eighteen months.

It was shown by monthly inoculations with these two fungi that there were seasonal variations in the susceptibility of Cox's Orange Pippin shoots to infection by *G. perennans*. The duration of active growth of the fungus was apparently determined by the ability of the host to isolate the affected tissues, and this was at a maximum during the summer months. The large number of successful inoculations with spore suspension during the winter further emphasized this fact. No expansion beyond the limits of the first layer of callus has been observed.

EXPERIMENTAL PROCEDURE.

In the thirteen-month period June 1953–June 1954, 130 inoculations with mycelium and 200 with spore suspension were made with both *G. album* and *G. perennans* on 8-year-old dwarf pyramid Cox's Orange Pippin trees. For the first seven months 30, and thereafter 20, inoculations with each species were made each month. The length of cankers induced was recorded monthly until January 1955, and then at intervals of two months until January 1956. Observations made on the production of acervuli during 1954 were followed in 1955 by the collection of water-borne conidia from actively sporing cankers.

The method and materials used in the inoculations have already been described (3). Spore collections were made by directing into tubes the rain water running down branches which bore cankers resulting from inoculations. A number of V-shaped pieces of 1 mm. aluminium sheet were bent to form gutters 1 cm. wide at the upper end, tapering to 2 mm. wide at the base. The sides were extended at the top and bent over so as to hold the gutters in contact with the branches. The lower end of each gutter was held in the mouth of a test tube supported in a wire spiral also attached to the branch (Fig. 6).

Whenever possible, the collecting tubes were changed before becoming full and the contents centrifuged. After pouring off the water, 1 ml. of distilled water was added and the mean taken of four counts of the number of spores present. For periodical germination tests 1 ml. of 1 per cent. dextrose solution was added and, after the counts had been made, the spore suspension was diluted, if necessary, to 50,000 spores per ml. The percentage germination was assessed after 18 hours at 25° C.

Results.

Development of cankers following inoculations.

G. album. When inoculations of apple shoots were made with *G. album*, cankers were induced only by inoculations in July, August and September, and then only to a limited extent. With spore suspensions, 10 per cent. of the inoculations were successful in July and 15 per cent. in August. With mycelium, the figures were 20 per cent. for August and for September. No externally visible development of cankers occurred before November and growth ceased 2–3 months later. Isolation of the infected tissues was complete by the spring, when none of the lesions had grown more than one inch. None of these cankers produced spores.

G. perennans. With a single exception, all inoculations with mycelium of *G. perennans* were successful throughout the year. Although recorded as unsuccessful after one month, all those made in January 1954 subsequently resulted in cankers. By contrast, inoculations with spore suspensions were completely successful only during November* (Fig. 1).

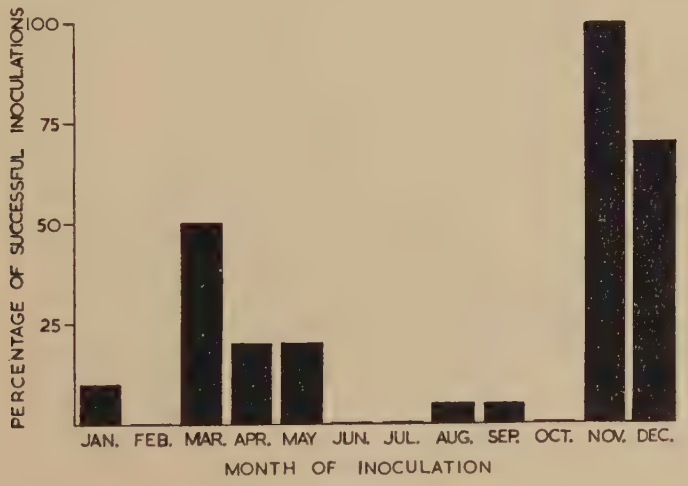

Fig. 1.
Percentage of successful inoculations with spore suspensions of *G. perennans*.

It seems probable that the low levels of infection in January and February were due to adverse weather conditions during these months, since the effect on spore suspensions would be greater than that on mycelium under agar. The reasons for

* In the Annual Report of the Long Ashton Research Station for 1954, the percentages of successful inoculations for the period January–June 1954 were given as half the actual figure.

the low percentage of successful infections resulting from spore inoculations during the summer are discussed later.

All actively growing cankers were successfully isolated by callus formation during the summer and no increase in length was observed after the September following inoculation.

Growth rate of mycelial cankers.

Since the inoculations and records of length were made about the middle of each month, direct comparisons of rates of growth were possible only after allowance had been made for variation in the length of the intervals. The calculated average length of each group of mycelial cankers at successive intervals of 28 days from inoculation (which approximates to that actually recorded) is given in Fig. 2.

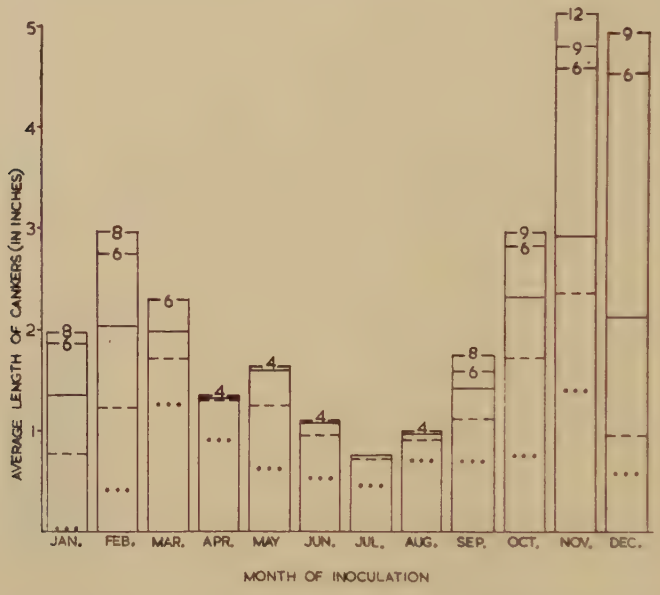

FIG. 2.

Average length of cankers induced by monthly inoculations with mycelium of *G. perennans*:
· · · length after 28 days,
– – – length after two 28-day periods,
—— length after three 28-day periods.
Subsequent increase in length is shown after numbered intervals of 28 days until no further increase occurred.

Fig. 2 illustrates three main points. First, with the exception of December, January and February, growth during the first 28-day period after each mid-monthly inoculation reflects the eventual total growth of the cankers induced. Secondly, again excluding these months, the relatively high rate of growth in the first period, compared with that in subsequent periods, suggests that the agar on which the inoculum was grown provided the fungus with essential nutriment after inoculation and, particularly during the summer months, assisted in the establishment of infection.

The low growth rate for the period mid-December to mid-March can probably be attributed to low temperature : the mean temperature was 37·7° F. in January, and 39·1° F. in February, 1954.

Lastly, July-initiated cankers grew least and for the shortest time whereas those of November grew fastest and for the longest time. Also, with the exception of November, December and March cankers, total growth over the fourth, fifth and sixth periods of 28 days was no more than in the third 28-day period alone. November and December cankers showed a similar reduction in the rate of growth only after six 28-day periods. The prolonged period of increase in length of cankers initiated between September and February was probably due to the death of the branches inoculated. It was characteristic of almost every canker induced during this period that it rapidly encircled the branch, killing the distal portion, and that extensive die-back followed (Fig. 6, c). This increase in total length at the proximal end of the dead portion of a branch was recorded, but after the sixth 28-day period the average increase was no more than 0·4 inch.

As has been stated, inoculations were made at about the middle of each month. Fig. 3 shows the total average growth of all the mycelial cankers in each month of the

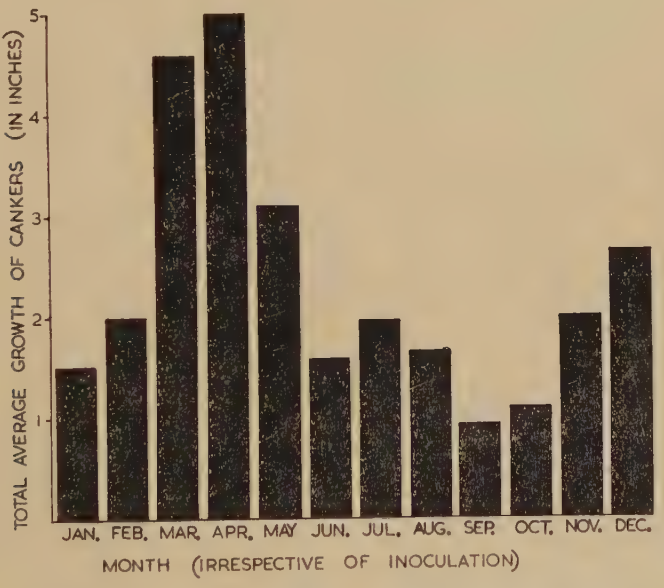

Fig. 3.

Total average increase in length of all mycelial cankers of *G. perennans*, irrespective of the month of inoculation.

year, irrespective of the month of inoculation. Corrections have been made so that the growth of new cankers is that which would have occurred if inoculation had taken place on the 15th of each month.

It has already been suggested that low temperatures had an adverse effect on infection and on the rate of initial growth in the period December-February ; they also appeared to impose some restriction on the rate of growth of established cankers.

In March and April, before full host activity had recommenced, the fungus grew vigorously but, as the level of host activity increased during the summer months, the rate of fungal growth decreased. In the autumn (October–December) the opposite effect was observed. It appeared that, subject to modifications imposed by extremes of temperature, the rate of growth of the fungus was determined by the level of host activity, a high level of activity being marked by an ability to isolate the infected tissues rapidly and completely (see Discussion).

Sporulation on cankers.

Observations on the development of acervuli were included in the mid-monthly records obtained after inoculation. A second series of cankers induced by monthly inoculations was also examined for sporulation.

The percentage of sporing cankers from each group of monthly inoculations is given in Table I.

TABLE I.

Percentage of sporing cankers from each group of monthly inoculations.

Month of inoculation	1953							1954					
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
Percentage of cankers producing acervuli	13	0	7	23	10	47	57	45	35	50	40	50	15

The monthly percentage of sporing cankers, irrespective of the month of origin, is given in Table II.

TABLE II.

Monthly percentage of sporing cankers.

Month of record	Percentage of cankers producing acervuli		
	1953	1954	1955
January	—	5	0·5
February	—	6·5	*
March	—	5	0·25
April	—	1	*
May	—	*	5·5
June	—	22	*
July	—	19	0·5
August	—	11	*
September	—	8·5	*
October	—	0	*
November	—	*	*
December	2	0	*

* No record.

From these observations it appeared that most of the cankers on which acervuli developed were initiated between November 1953 and May 1954, and that the largest number of sporing cankers was present between May and July 1954, the year following inoculation. By May 1955 very few cankers were still active and these were all initiated in the period November 1953–March 1954.

Records of spore production.

Examination of artificially-induced cankers for the start of sporulation was begun in April 1955, and on 7th May a number of water traps were placed in position, as described above. After a preliminary period in which conidia were collected from some cankers which showed no external sign of active sporulation, while others which were apparently active produced no spores, nine sporing cankers of various ages had been selected. Continuous collection of conidia was begun by the end of May, one set of tubes being replaced by another.

The age and origin of each of the cankers selected, together with the total number of spores collected from each in the period 25th May–30th November 1955, are given in Table III.

Table III.

Age and origin of cankers in relation to spore production.

Number of cankers	Month of origin	Inoculum	Total number (thousands) of spores collected in period 25/5/55–30/11/55
1	September 1953 ..	Spore suspension ..	543
2	November 1953 ..	Mycelium	1,755
		Spore suspension ..	445
2	December 1953	Mycelium	228
		Spore suspension ..	1,677
1	January 1954	Mycelium	2,350
1	February 1954	Mycelium	449
2	March–April 1955 ..	Natural infections (a) ..	688
		Natural infections (b) ..	5,456

All the sporing cankers selected for study originated during the period September–April ; no sporulation was detected on cankers induced during the summer months. With the exception of one canker resulting from a natural infection, 18-month-old cankers sporulated as vigorously as younger ones, and those of about the same age showed similar variations in spore output, irrespective of the month of origin. A typical sporulating canker is illustrated in Fig. 7.

The periods during which collection was made were of variable length, ranging up to fourteen days according to the rainfall. The number of conidia collected during such periods, together with the daily rainfall between 1st August and 21st October 1955, are shown in detail in Fig. 4. Although some rain was needed for

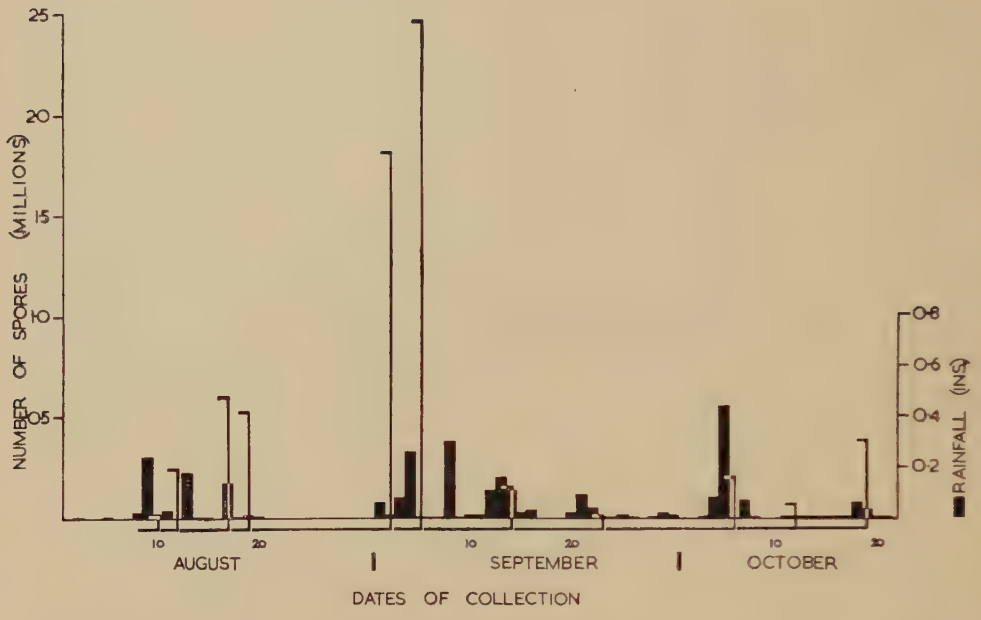

FIG. 4.

Spore collection in relation to daily rainfall during the period 1st August–21st October 1955. Vertical lines give total numbers of conidia collected over the periods shown by horizontal lines below x-axis.

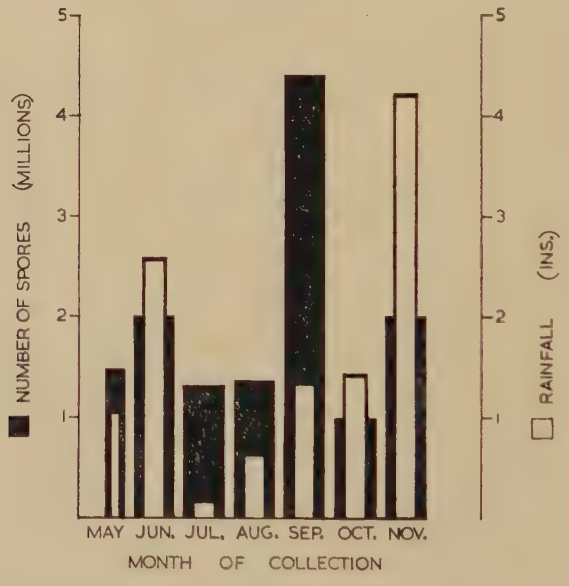

FIG. 5.

Total monthly spore collections in relation to monthly rainfall during the period mid-May to 30th November 1955.

the dissemination of the conidia, there was no apparent correlation between the amount of rain and the number of conidia collected.

The total monthly rainfall and the total number of conidia collected each month from May to November 1955 are assembled in Fig. 5. For the month of May, the rainfall shown was recorded after the 25th, when spore collection from the selected cankers was begun. Here again the number of conidia collected bore no apparent relation to the amount of rain recorded during each month.

DISCUSSION.

Swarbrick (9) showed that the ability of an apple tree to respond to the wounding caused by pruning, and to form barriers effective against invasion of the woody tissues by parasitic organisms, depended on the time of year when the wound was made. Whereas wounded parenchymatous tissue was protected by suberization after 2–3 days, protection of the woody tissues by the deposition of insoluble substances might take six months. He further pointed out that, although this protective barrier was formed during the normal healing process, it could also be induced by fungal invasion, for such a barrier was frequently present in cells surrounding those invaded by fungi. Short pieces of stem, in which the wood cells were so blocked by insoluble substances that no air could pass through them under pressure, were therefore considered to be completely protected against invasion by parasitic organisms.

When pruning wounds were made in the period late May–late August, Swarbrick found that blocking of the wood cells had begun after 10 days and was completed after 4–5 weeks. Wounds made in September and October remained partly blocked, while those made between November and April remained quite unaltered until May, when blocking of the cells in all these wounds was completed.

It is significant that the period during which inoculations of pruning wounds with spores of *G. perennans* were most successful was that in which no healing of the woody tissues takes place. During the period May–August, when maximum growth and sap movement and rapid closing of the wounded tissues by gums occur, the number of successful inoculations was lowest. In September and October, when only partial blocking occurs, spore inoculations were only partly successful.

If, as has been suggested, the extent to which *G. perennans* can invade pruning wounds is governed by the speed with which the host can isolate the infected tissues, some penetration of the woody tissues is implied, since wounds in the cortex have acquired some protection after 2–3 days. McLarty (7) identified mycelial strands in the tracheae and stated that invasion of the xylem could take place at any time of year but only through a wound. He also stated that infections of the phloem spread only in the late winter and early spring. The inoculations of bark wounds with mycelium, described above, showed growth mainly between September and March.

Wilkinson (14) inoculated Cox's Orange Pippin shoots with mycelium of *G. perennans* in November, by the method described above for spore suspension inoculations. He reported considerable growth of the fungus until the end of December, with renewed growth in the spring and completion of callus formation by mid-April. Similar inoculations in early May resulted in cankers which grew more slowly and which were, by the autumn, permanently isolated by callus.

These results agree with the writer's and with those of a number of workers in N. America whose investigations prior to 1933 were summarized by McLarty.

The view generally held was that the apple tree is most susceptible to infection by *G. perennans* in the autumn, especially during November. Some workers also reported the failure of inoculations made in the period January–August, which suggests that the strain of the fungus common on the American continent may be less parasitic than that in this country. However, the results given in this paper indicate that *G. perennans* is only weakly parasitic, and alterations in conditions might readily favour the parasite or its host. Its ability to infect uninjured tissues following spring inoculations in this country, in contrast with its failure to do so in North America, is probably due to small changes in the host-parasite relationship brought about by differences in weather conditions.

Many workers referred to by McLarty found that aphis and frost injuries were particularly important factors in the establishment of infections, and that devitalization through any cause resulted in a more serious attack.

Wilkinson (10, 11) reported a serious die-back of trees in a Warwickshire orchard which had been pruned during the summer, and stated that the substitution of winter for summer pruning eliminated *G. perennans* from the affected trees. The winter pruning was carried out thoroughly at Wilkinson's suggestion and all infected branches removed and burned, a process which in itself would do much to control the disease. Hobbis states (private communication) that labour was scarce at the time and that, when summer pruning was carried out, little attempt was made to do more than shorten shoots where necessary. In this way large numbers of snags were probably left to die back to the next bud, thus providing abundant devitalized tissue for infection by fungi.

Wilkinson reported cankers one inch in length in early September, from which *G. perennans* was isolated. This, however, does not necessarily mean that the fungus was alone responsible for the extent of the die-back. The prolonged increase in length, described above, of cankers induced in November and December has been attributed to the death of the distal portion of the inoculated branches. This elongation occurred only on these branches and at a time when all other cankers had been completely isolated by callus.

It seems possible, therefore, that the infections of summer pruning wounds described by Wilkinson took place some time after the wounds were made. It has been shown that devitalized tissues are especially prone to infection (Brown, 2 ; McLarty, 7), and dying pruning snags would seem to be highly liable to infection in the presence of spores of the fungus.

Swarbrick (9), as a result of his findings, suggested that pruning should be done during the summer, since at this time of year the reaction of the tree to wounding is vigorous enough to isolate the exposed woody tissues quickly and completely. Brooks and Moore (1) found that the infection of plum trees by *Stereum purpureum* occurred readily at any time except during June, July and August. The formation of gum barriers following wounding and infection was so vigorous during these months that many trees were able to isolate the affected tissues completely.

The evidence suggests, therefore, that extensive infections of pruning wounds are most likely to follow pruning in the autumn. Edney (4) states that during the last three years infections have frequently been observed on bush fruit trees pruned during the winter. According to McLarty, some workers in North America have suggested that pruning should be done as late as possible in the spring, so that the period before the complete isolation of any infected tissues is short. In this

PLATE I

Fig. 6.

Top of dwarf pyramid Cox's Orange Pippin tree inoculated with *G. perennans* in November 1953. Water traps for the collection of water-borne conidia are shown in position.

a, point of inoculation with mycelium.
a¹, points of inoculation with spore suspension.
b, branches killed by natural infections in 1954.
c, extent of die-back from points of inoculation.

[*face p. 280*

PLATE II

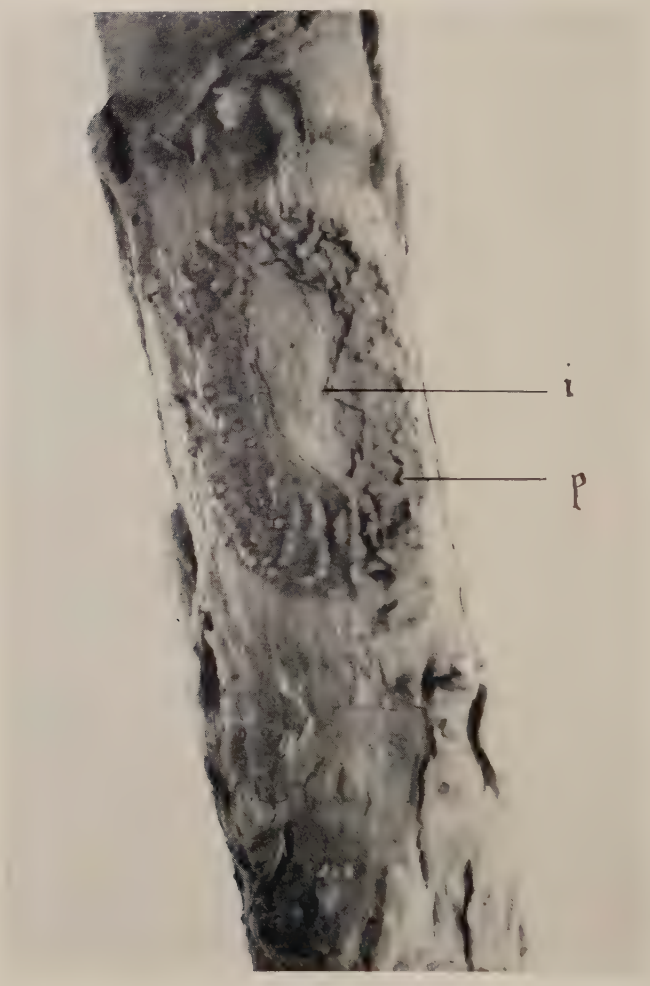

FIG 7.

Three-month-old canker induced by inoculation with *G. perennans* in April 1954, showing distribution of acervuli.
i, site of inoculation.
p, acervulus.

country, however, there appears to be some danger of infection in the spring, as infections have been found to occur fairly readily in March, April and May (Corke, 3 ; Edney, 4 ; Wilkinson, 14).

The failure of most of the spore inoculations in January and February described above has been attributed to the low temperature experienced in 1954. This, combined with a virtual absence of spores also noted by Edney, suggests that in this country these are the most advantageous of the winter months in which to prune.

Marsh (6), as a result of experiments on the infection of pruning wounds by *Nectria galligena* Bres., also recommended that pruning be carried out during cold dry weather. The similarity of these conclusions exemplifies the wide measure of agreement between the results described here and those obtained earlier at Long Ashton by a number of workers engaged in studies of *N. galligena*. Such agreement is not unexpected in the host-parasite relationships of two fungi which, while differing in their specific biology, produce similar symptoms and reactions in the same host.

Until the results of work on the protection of fruit against infection by *G. perennans* are available, it seems reasonable to suggest that the general measures recommended for the control of cankers of *N. galligena* would be the most likely also to reduce the incidence of the bitter rot fungi.

Observations by the author on the development of acervuli suggested that sporulation occurred on more than one-third of the artificially-induced cankers, and the selection of sporing cankers for the collection of water-borne conidia between May and November 1955 showed that all the active ones had been induced by winter inoculations. Acervuli were present throughout most of the year, the number of cankers bearing acervuli being at a maximum between May and July following inoculation. Reduction in the number of sporing cankers after September was due to the failure of acervuli to develop on new cankers before December.

Wilkinson (14) reported acervuli in May following inoculations in November, and in July on cankers induced in May. Edney, however, found spores after six weeks when inoculations were made on 1st May. He also collected abundant water-borne spores from that date until late September and noted a fall in the number produced until the end of February, when production ceased.

As shown above, conidia were produced at a fairly constant rate throughout the summer of 1955, with a reduction after a drought in July and August. The number collected in early September was more than twice that in other months, although the rainfall was moderate. It is suggested that the gradual reduction in the rate of growth, and the final isolation of increasing numbers of cankers during the summer, resulted in a change from the parasitic to a saprophytic phase, with an increased tendency to sporulation.

McLarty stated that, in cankers which were active in March, the fungus ceased to be parasitic in the phloem when the buds had become green at the tip, and that the ensuing saprophytic stage on the dead tissues gave rise to acervuli one month later. He also found that viable conidia were produced from wood which had been dead for 2 years. The collection of conidia from cankers nearly 2 years old, as described by the writer, is attributed to the size attained by winter-induced infections before isolation of the infected tissues was complete. Limited sporulation was observed on cankers resulting from inoculations in June, July or August, all of which were soon isolated by callus.

The small number of short-lived, non-sporing cankers induced at Long Ashton

in 1953–54 by the monthly inoculations with *G. album* described in this paper indicates that this species is not parasitic. Ogilvie (8) and Wilkinson (12) reported its occurrence as a saprophyte on snags, although Edney also found it parasitizing healthy tissue and occurring on cankers resulting from infections by other fungi. *G. album* has been stated to be less important than *G. perennans* in this country in causing losses of stored fruit (Edney, 4 ; Wilkinson, 15), but the frequency of its occurrence on fruit at present seems to be inconsistent with its apparent absence from orchards.

SUMMARY.

Monthly inoculations of Cox's Orange Pippin shoots showed that between June 1953 and June 1954 the ability of *Gloeosporium perennans* to invade healthy tissue was greatest during the winter. The cankers induced continued to grow until the following autumn, whereas cankers induced during the summer were rapidly and permanently isolated by callus.

September was the month of minimum growth and no subsequent resumption of growth was observed. This is suggested as the cause of an increased tendency to sporulation, and a rise in the number of conidia collected in rain water, during September.

Acervuli developed on cankers of all ages, almost throughout the year, and viable conidia were readily collected from mid-May to December.

The results are discussed in relation to the time of pruning.

Inoculations with *G. album* indicated that this species was not parasitic on wood, and suggested that its frequent occurrence on fruit was wholly due to its ability to exist saprophytically at other times.

ACKNOWLEDGMENTS.

The author wishes to thank Miss M. Marlow for her assistance in making the inoculations and recording the results ; also Mr. J. S. Miller and Miss M. Waller for collecting and counting the water-borne conidia from May to June and June to December respectively. The meteorological records were kindly made available by Mr. G. E. Clothier and the photographs taken by Mr. G. Jones.

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MOLYBDENUM AS A PLANT NUTRIENT

VII. THE EFFECTS OF DIFFERENT MOLYBDENUM AND NITROGEN SUPPLIES ON YIELDS AND COMPOSITION OF TOMATO PLANTS GROWN IN SAND CULTURE

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EXPERIMENTS with cauliflower plants (3) have shown that molybdenum deficiency causes decreased yields and abnormal leaf growth or whiptail symptoms irrespective of whether nitrogen is given as nitrate, nitrite, ammonium compounds, urea or glutamic acid. The concentrations of ascorbic acid and of some sugars are also decreased in the same circumstances but chlorophyll content and total organic nitrogen are appreciably decreased by molybdenum deficiency only when nitrogen is given as nitrate. It was concluded from these results that molybdenum is still required as an essential element by cauliflower under conditions in which impaired nitrate assimilation is not the factor limiting growth.

The experiments described here were carried out in 1953 (10) to investigate whether the conclusions drawn for cauliflower were applicable to other plants. Tomato was chosen as it does not show whiptail symptoms, which might have caused the decreased yields of the cauliflower plants (3) and which have so far been found to be associated only with brassica species (6, 8, 9).

EXPERIMENTAL.

Tomato plants, variety Market King, were grown in sand culture by methods already described (3, 5). Three plants were grown in each pot. There were six replicates, each of one pot per treatment, arranged in randomized blocks as a factorial experiment with a split-plot arrangement with respect to molybdenum supply. Molybdenum was given at 0·05 p.p.m. or was omitted from the nutrient which, together with the sand, provided the equivalent of approximately 0·00001–2 p.p.m. Mo. Nitrogen was given as nitrate, nitrite, ammonium sulphate, ammonium nitrate, ammonium nitrite, urea or glutamic acid at 12 mM/l. To prevent ammonium injury (3) calcium carbonate was mixed with the sand in each of the above treatments. An extra treatment, namely nitrate without calcium carbonate, was included as a test for possible contamination by molybdenum or other effects of the calcium carbonate addition. The composition of the nutrient solutions and the methods of purification were the same as those used previously ; the solution contained 8 mg. eq. l. of calcium chloride (3).

Yields were recorded as total dry weight and the percentage of dry matter in whole plants was also determined. Ascorbic acid, dehydroascorbic acid, chlorophyll and nitrate contents were estimated as described previously (1, 2, 3).

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RESULTS.

Visual symptoms.

All plants given molydenum grew normally and showed no deficiency symptoms.

In the molybdenum-deficient series, plants given nitrate showed in acute form the typical symptoms already described (6, 8, 9), namely yellow-green or yellow interveinal mottling, rolling and upcurling of leaf margins, followed by apical, marginal and general pale brown necrosis and withering. The symptoms began in the apical leaflet of oldest leaves and progressed regularly to lateral leaflets and younger leaves. Similar symptoms appeared in plants given ammonium nitrate. They were less severe in some of these plants and the green areas of lamina adjacent to the main veins were usually somewhat darker than in plants given nitrate only. Slight interveinal mottling was seen occasionally in a few plants given ammonium sulphate or ammonium nitrite.

Two other symptoms were observed in some plants. These were confined entirely to plants grown without molybdenum and not given nitrate or ammonium nitrate. One symptom occurred in old leaves, which showed narrow dark brown areas around the margins of leaflets. This was most marked in plants given glutamic acid but also occurred in those given nitrite or urea. The other symptom was mainly seen in fully expanded mid-stem leaves, the apical leaflets of which wilted suddenly. The wilted areas rapidly dried out but remained dull green or grey-green and did not develop brown scorch. Leaves which showed this symptom were free from the mottling associated with plants given nitrate. These symptoms were most marked in plants given nitrite or urea.

Yields and dry matter content.

Data presented in Table I show that, in all nitrogen treatments, yields were decreased by omission of molybdenum. The differences were highly significant ($P < 0{\cdot}001$) for all treatments except ammonium sulphate, for which lower significance was found ($0{\cdot}01 < P < 0{\cdot}05$). The interaction between molybdenum level and nitrogen supply was also highly significant ($P < 0{\cdot}001$).

The greatest yield in the presence of molybdenum was obtained with urea and the least, only 60 per cent. of that with nitrate, was obtained with glutamic acid. Differences in yield between different nitrogen treatments were often significant in both the normal and molybdenum-deficient series of treatments, but in the normal series growth as a whole was satisfactory with each of the nitrogen sources, except glutamic acid.

The percentage dry matter in the plants was markedly decreased by molybdenum deficiency in some nitrogen treatments. The differences were highly significant ($P < 0{\cdot}01$ or $< 0{\cdot}001$) for nitrate, nitrite, ammonium nitrate and ammonium nitrite. The difference was less significant ($P < 0{\cdot}05$) for ammonium sulphate, and no difference in dry matter content occurred in the urea and glutamic acid treatments. Differences between dry matter content in different nitrogen treatments were often significant in both the normal and molybdenum deficiency series. The interaction between molybdenum level and nitrogen supply was highly significant ($P < 0{\cdot}001$), and was seen by inspection to be due partly to the difference in behaviour between plants given urea or glutamic acid and the rest, and partly to the much larger effects of molybdenum observed in plants given nitrate.

TABLE I.

Effects of molybdenum and source of nitrogen on total yield, per cent. dry matter, chlorophyll and nitrate contents of leaves of tomato plants grown in sand culture. (Means of six replicates.)

Nitrogen source	Yield gm. dry weight		Dry matter per cent.		Chlorophyll mg./100 gm. fresh weight		Nitrate per cent. in dry matter	
	−Mo	+Mo	−Mo	+Mo	−Mo	+Mo	−Mo	+Mo
Nitrate	12·8	23·8	11·1	16·9	11·1	18·1	5·18	1·06
Nitrate and $CaCO_3$	9·6	25·0	8·4	16·9	8·9	15·8	7·29	0·87
Nitrite and $CaCO_3$	9·5	18·7	13·2	15·8	17·9	19·9	1·11	0·65
Ammonium sulphate and $CaCO_3$	15·9	19·4	13·6	15·9	21·6	17·4	1·04	0·58
Ammonium nitrate and $CaCO_3$	13·7	23·6	10·9	17·7	12·9	17·0	4·75	1·09
Ammonium nitrite and $CaCO_3$	13·9	21·9	13·7	17·8	17·9	15·9	1·60	0·88
Urea and $CaCO_3$	12·3	27·6	14·5	15·0	16·9	18·7	0·85	0·92
Glutamic acid and $CaCO_3$	6·8	15·0	16·8	16·5	14·5	16·6	0·67	0·83
L.S.D., Mo effect :								
$P<0·05$	3·3		2·0		2·7		0·90	
$P<0·01$	4·5		2·7		3·8		1·22	
$P<0·001$	6·3		3·8		5·4		1·68	
L.S.D., N effect :								
$P<0·05$	3·0		1·8		2·4		0·86	
$P<0·01$	4·0		2·4		3·2		1·14	
$P<0·001$	5·1		3·2		4·2		1·48	

CHLOROPHYLL.

Chlorophyll content, shown in Table I, was decreased by molybdenum deficiency only in plants given nitrate or ammonium nitrate ($P<0·001$ or $<0·01$). Plants given ammonium sulphate without molybdenum contained significantly more chlorophyll than those given molybdenum ($P<0·01$). The interaction between molybdenum level and nitrogen supply that appeared in the contrast between the effects of molybdenum in the nitrate, as against the other nitrogen treatments, was highly significant ($P<0·001$). In the presence of molybdenum, the differences in chlorophyll content between plants given different nitrogen treatments were mainly small but sometimes significant, and the concentration was greatest in plants given nitrite.

ASCORBIC ACID AND DEHYDROASCORBIC ACID.

Ascorbic acid concentrations in leaves, shown in Table II, were decreased in all nitrogen treatments by omission of molybdenum. The effects of molybdenum as a whole, and on the difference between the means for sources of nitrogen other than nitrate, were highly significant ($P<0·001$). Differences for plants given nitrate, ammonium nitrate, ammonium sulphate or ammonium nitrite were individually highly significant ($P<0·001$ or $<0·01$). The difference in concentrations for plants given glutamic acid was also significant ($P<0·05$), but differences for plants given nitrite or urea did not attain significance.

Molybdenum deficiency produced decreases in dehydroascorbic acid similar to, and commonly rather greater than, those in ascorbic acid. The error variance was,

Table II.

Effects of molybdenum and source of nitrogen on content and relative proportion of ascorbic acid and dehydroascorbic acid in tomato plants grown in sand culture. (Means of six replicates.)

Nitrogen source	Ascorbic acid mg./100 gm. fresh weight		Dehydro-ascorbic acid mg./100 gm. fresh weight		Total mg./100 gm. fresh weight		Ascorbic acid as per cent. of total	
	−Mo	+Mo	−Mo	+Mo	−Mo	+Mo	−Mo	+Mo
Nitrate	48·2	89·0	51·0	105·4	99·1	194·5	48·9	46·5
Nitrate and $CaCO_3$	27·4	82·6	31·2	87·9	58·5	170·6	46·7	48·5
Nitrite and $CaCO_3$	67·4	79·4	74·5	90·4	141·9	169·8	47·5	47·1
Ammonium sulphate and $CaCO_3$	63·2	88·0	62·8	95·6	126·0	183·6	50·4	48·0
Ammonium nitrate and $CaCO_3$	43·7	86·8	52·0	92·8	95·8	179·6	46·4	48·4
Ammonium nitrite and $CaCO_3$	63·6	86·3	65·4	99·4	129·0	185·7	49·3	46·5
Urea and $CaCO_3$	68·1	79·8	74·3	90·8	142·4	170·6	47·8	47·0
Glutamic acid and $CaCO_3$	67·9	85·9	76·4	92·6	144·2	178·5	47·7	48·1
L.S.D., Mo effect :								
$P<0·05$	15·4		25·1		39·0		3·7	
$P<0·01$	22·0		36·4		56·5		—	
$P<0·001$	32·8		55·2		85·7		—	
L.S.D., N effect								
$P<0·05$	11·8		17·8		27·9		2·8	
$P<0·01$	15·7		23·6		37·1		—	
$P<0·001$	20·4		30·6		48·2		—	

however, greater so that in general the differences did not attain such high levels of significance. The interactions between molybdenum level and nitrogen supply were also highly significant ($P<0·001$ or $<0·01$) for ascorbic and dehydroascorbic acids. The interactions were shown by the larger effects of molybdenum in the presence of nitrate or ammonium nitrate than of the other sources of nitrogen. The proportion of ascorbic acid in the total ascorbic and dehydroascorbic acids was notably constant, ranging from about 46·5 to 50·5 per cent. of the total, and was not significantly affected by molybdenum or nitrogen supply. The nitrogen treatments had no significant effects upon the concentrations of ascorbic or dehydroascorbic acids in the presence of molybdenum.

Nitrate content.

As shown in Table I, nitrate accumulation attained significant proportions only in molybdenum-deficient plants given nitrate or ammonium nitrate ($P<0·001$). All plants contained appreciable concentrations of nitrate but, in the presence of molybdenum, these concentrations were not significantly affected by nitrogen supply. The interaction between molybdenum and nitrogen supply was highly significant ($P<0·001$).

DISCUSSION.

The results described here show points both of similarity to, and contrast with, those obtained with cauliflower. The effects of molybdenum deficiency on growth, chlorophyll content and ascorbic acid concentration resembled those found with

cauliflower (1, 3) in the presence of all sources of nitrogen tested. While the proportion of ascorbic to dehydroascorbic acid in tomato was about 1·0 to 1·1, as compared with about 1·0 to 0·1 or 0·2 in cauliflower, there was no evidence to suggest that molybdenum status affected this ratio in tomato, although small but significant changes in the ratio occurred in cauliflower.

The visual symptoms observed in tomato plants deficient in molybdenum but given nitrate or ammonium nitrate (6, 9) were similar, and clearly analogous with those shown in cauliflower plants grown in similar treatments (3, 6, 8)—namely, interveinal mottling, marginal curling, necrosis and withering of older leaves. On the other hand, the absence or scarcity of clear or characteristic symptoms in plants given the other sources of nitrogen was in marked contrast with the occurrence of the secondary symptoms of whiptail observed in cauliflower plants given similar treatments (3). It appears from this that the decreases in yields observed in both sets of experiments are due to some general effect of molybdenum deficiency on growth and that the production of whiptail is a specialized response apparently confined to brassica species.

Molybdenum does not appear to be necessary for chlorophyll production in tomato or in cauliflower (3), provided nitrogen is available in a form that does not directly involve the mediation of nitrate reductase (12) for its assimilation. On the other hand, decrease in ascorbic acid is shown to be a general effect of molybdenum deficiency and the conclusion drawn previously (1, 3), that this decrease is independent of chlorophyll content, is confirmed here.

The highly significant interactions between molybdenum level and nitrogen supplies in respect of yields, and of chlorophyll and ascorbic acid contents, show that the molybdenum requirements of the tomato are quantitatively greater when plants are grown with nitrate or ammonium nitrate than when grown with other ammonium compounds or with nitrite, urea or glutamic acid, but the evidence shows equally that molybdenum is still required by tomato plants when given nitrogen in the latter forms.

Estimation of the molybdenum content of cauliflower plants grown simultaneously in parallel experiments (3), in which the *same* nutrient reagents were used, showed that the differences in behaviour between plants given nitrate or ammonium nitrate, and those given the other nitrogen sources, were not due to the introduction of additional molybdenum in the last group of treatments.

From the results obtained here, and in earlier experiments with cauliflower, rape, kale and tomato (3, 4, 6), it is seen that molybdenum-deficient plants grown with ammonium nitrate, or with an equal amount of nitrogen as nitrate plus nitrite, show in many respects a greater resemblance to those grown with the equivalent amount of nitrogen as nitrate only than to those grown with ammonium sulphate, ammonium nitrite, nitrite, urea or glutamic acid as sources of nitrogen. Molybdenum-deficient plants grown with nitrate are, however, able to produce abundant soluble nitrogen compounds when subsequently given ammonium sulphate (11), and deficient plants grown with ammonium nitrate, or nitrate and nitrite in equal amounts, contain apparently adequate concentrations of many amino acids and total organic nitrogen (7). Molybdenum deficiency may therefore involve three distinct although possibly interacting effects. First, organic nitrogen production by plants grown with nitrate only is decreased (2, 3), and may be a limiting factor. Second, nitrate accumulation itself may be injurious in molybdenum-deficient plants, even where other sources of

nitrogen are available at levels adequate to produce organic nitrogen compounds. Third, growth and the concentrations of certain metabolic products, as for example ascorbic acid, may be decreased in plants in a general manner which is not dependent on the source of nitrogen used and which does not necessarily involve specific leaf injury, such as that leading to whiptail in brassica plants.

SUMMARY.

1. Tomato plants, variety Market King, were grown in sand culture at deficiency and normal levels of molybdenum with nitrate, nitrite, ammonium nitrate, ammonium nitrite, ammonium sulphate, urea or glutamic acid as source of nitrogen.

2. Typical symptoms of molybdenum deficiency were observed in acute form only in plants given nitrate or ammonium nitrate. Plants grown with the other nitrogen sources in the absence of molybdenum were mainly devoid of such symptoms, though a few showed wilting of leaflets which later dried out but remained green, and slight mottling appeared temporarily in some plants. Plants given molybdenum were normal in appearance.

3. Molybdenum deficiency decreased yields significantly in all nitrogen treatments.

4. The percentage dry matter in the plants was also significantly decreased by molybdenum deficiency in all treatments except those with urea or glutamic acid.

5. Chlorophyll content was significantly decreased by molybdenum deficiency *only* in plants given nitrate or ammonium nitrate. There was a significant increase in chlorophyll content of deficient plants given ammonium sulphate.

6. Ascorbic and dehydroascorbic acid concentrations were decreased, usually to a significant extent, by molybdenum deficiency in all nitrogen treatments. The ratio of ascorbic to dehydroascorbic acid was about 1·0 to 1·1 and was not affected by molybdenum level or nitrogen source.

7. Nitrate accumulated to over 7 per cent. by weight of dry matter in molybdenum-deficient plants given nitrate and to nearly 5 per cent. in those given ammonium nitrate. All plants given molybdenum and those given the other sources of nitrogen without molybdenum contained appreciable concentrations of nitrate, but the levels did not differ significantly.

8. The interactions between molybdenum level and nitrogen source were highly significant for yields, dry matter, chlorophyll, nitrate, ascorbic acid and dehydroascorbic acid contents.

9. It is concluded that molybdenum is required by tomato for normal growth, irrespective of the form in which nitrogen is supplied, but that the requirement is greater in the presence of nitrate or ammonium nitrate than of other sources of nitrogen.

These results are discussed in relation to those from similar experiments carried out with cauliflower.

ACKNOWLEDGMENTS.

We are grateful to Mr. G. M. Clarke for the statistical analysis of the data obtained in this experiment and to Miss R. A. Paget for technical assistance.

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A NOTE ON THE RELATIVE ABUNDANCE OF FLEA BEETLES (*PHYLLOTRETA* STEPHENS AND *PSYLLIODES* BERTHOLD) ON DIFFERENT CRUCIFEROUS CROPS

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It is well known that the relative abundance of flea beetle species on cruciferous crops varies with time and place and there is evidence that it may also vary from one type of crop to another (Newton, 1928 ; Haddock, 1945). Variations from crop to crop have never been satisfactorily demonstrated ; during 1953, therefore, an experiment was carried out at Wye College to compare the populations on six different crops. Considerable differences were found.

Methods.

Plots of turnip, cabbage, cauliflower, radish, swede and white mustard were sown together in 4 randomized blocks. The sowing date was 31st March. Each plot consisted of 4 rows of plants and was 5 metres long and 2·5 metres wide. Observations were confined to the middle 3 metres of the two centre rows.

A random sample of beetles was taken from each plot every second day from 21st April to 29th May by means of an Ashton-Hayne flea beetle trap (Miles, 1944). Each sample contained all the beetles from a 30 cm. length of plant row. Plant counts and leaf area measurements were also made so that the numbers of beetles caught could be related to the total leaf area of the plants sampled. (The mustard had to be cut back owing to its high rate of growth ; therefore its leaf area was not measured.)

Results.

Ten species of flea beetles were found (Table I). The greatest numbers occurred on the largest crops (turnip, swede, mustard) and the least numbers on the smallest. Species varied greatly in abundance and only the five most common, which together formed more than 98 per cent. of the total catch, will be dealt with in detail.

Differences in composition of the populations on the crops were compared by analysis of variance between blocks and crops on the transformed data. The percentage catches were transformed to angles (Fisher and Yates, 1948), and weighted to compensate for the great variation in size of catches. The weighting coefficient was

$$\frac{\text{Block total} \times \text{crop total}}{\text{Total for blocks and crops}},$$

where the totals were those for all species.

Weighted mean percentages for each species on each crop were calculated and highly significant differences were found (Table II). Values which do not differ significantly are underlined. These differences showed that not all species were

TABLE I.

Total numbers of beetles caught (over 40 days) on various crops.

Species of beetle	Crop						
	Turnip	Swede	Cabbage	Cauli-flower	Mustard	Radish	Totals
Phyllotreta cruciferae (Goeze)	1,086	695	152	204	732	182	3,051
Phyllotreta atra (F.)	760	390	71	106	975	406	2,708
Phyllotreta undulata Kuts. ..	280	108	44	53	181	84	678
Phyllotreta nigripes (F.) ..	29	27	6	12	28	50	152
Phyllotreta nemorum (L.) ..	39	14	6	1	9	34	103
Phyllotreta consobrina (Curt.)	17	22	3	4	4	7	57
Phyllotreta diademata Foudr.	19	4	1	4	10	0	38
Phyllotreta aerea Allard ..	2	0	0	0	0	0	2
Phyllotreta nodicornis (Marsh)	1	0	0	0	0	0	1
Psylliodes cuprea (Koch) ..	0	1	0	0	0	0	1
Totals	2,161	1,261	283	384	1,939	763	6,791
Total leaf area of plants sampled over 40 days (in 1,000 sq. cm.)	58	50	5	6	—	16	

distributed similarly between the crops, and by expressing the catches as population densities, i.e. numbers of beetles per 1,000 sq. cm. of plant surface, the distribution of each species can be shown (Table III).

TABLE II.

Weighted mean percentages of five most abundant species on various crops.

Species of beetle	Crop						
	Turnip	Swede	Cabbage	Cauli-flower	Mustard	Radish	Signifi-cance level
P. cruciferae	50·5	55·2	53·7	53·8	37·9	23·2	0·1%
P. atra	34·9	30·8	25·1	25·9	50·2	53·0	0·1%
P. undulata	9·6	8·4	15·0	14·4	9·3	11·1	N.S.
P. nigripes	1·2	2·1	2·4	3·2	1·4	6·4	1%
P. nemorum	1·7	1·1	0·6	0·1	0·3	4·5	0·1%
Others	2·1	2·4	3·2	2·6	0·9	1·8	Not analysed

N.B.—Sets of figures underlined do not differ significantly.

Cabbage and cauliflower had the highest total population densities, radish and turnip were intermediate, and swede had the lowest. This was almost in inverse order to plant size and suggests that small plants are more attacked than large ones. The highest total populations, i.e. number of beetles per unit area of ground, occurred of course on the largest plants, as shown in Table I (cf. also McMahon, 1942). The highest density of *P. undulata* occurred on cabbage and cauliflower, and that of *P. atra*, *P. nemorum* and *P. nigripes* on radish. The population of *P. cruciferae* was

Table III.

Total population densities of five most abundant species of beetles over 40 days, i.e. total numbers of beetles caught per 1,000 sq. cm. of total leaf areas of plants sampled.

Species of beetle	Crop					
	Turnip	Swede	Cabbage	Cauli-flower	Mustard	Radish
P. cruciferae	18·7	13·9	30·0	34·0	—	11·4
P. atra	13·1	7·8	14·2	17·7	—	25·4
P. undulata	3·6	2·2	8·8	8·8	—	5·3
P. nigripes	0·5	0·5	1·2	2·0	—	3·1
P. nemorum	0·7	0·3	1·2	0·2	—	2·1
Others	0·7	0·5	0·8	1·3	—	0·4
Totals	37·3	25·2	56·2	64·0	—	47·7
Total leaf area of crop sampled (in 1,000 sq. cm.)	58	50	5	6	—	16

most dense on cauliflower and least dense on radish. No species was abundant on swede.

The differences in distribution of *P. atra* and *P. cruciferae* provide biological evidence that they are not varieties of the same species as was at one time believed by Börner and Blunck (1919).

It is not practicable to discover the reasons for the differences in distribution of the various species by field work alone ; influences such as different rates of growth and maturation of crops, which in themselves may affect distribution, cannot be controlled. In the present experiments some of these factors may have operated, e.g. the turnips attained a leaf area 4 times that of the cabbages, and the radishes were mature at the end of the observations whereas the cabbages and cauliflowers were still quite juvenile.

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SUMMARY.

Flea beetle populations were found to vary in composition on different adjacent cruciferous crops. The greatest numbers of beetles occurred on the crops with the largest plants but the greatest population densities (i.e. numbers of beetles per unit leaf area) occurred on the crops with the smallest plants. This suggests that small plants are more severely attacked than large ones.

The highest population density of *Phyllotreta undulata* (Kuts.) occurred on cabbage and cauliflower, and that of *P. atra* (F.), *P. nemorum* (L.) and *P. nigripes* (F.) on radish. The population of *P. cruciferae* (Goeze) was most dense on cauliflower and cabbage and was least dense on radish. Differences in distribution of *P. atra*

and *P. cruciferae* provide biological evidence that they are not varieties of the same species.

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A NOTE ON THE USE OF HONEY-BEES AS POLLINATING AGENTS IN CAGES

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THIS note describes equipment which makes it possible to use a queen-right colony of honey-bees to pollinate small numbers of plants without contamination from unwanted pollen and without abnormal loss of bees.

Bees are in fairly common use for the controlled pollination of crop plants. Techniques include the use of both humble- and honey-bees, confined in greenhouses, or in cages of wood and glass or of cheese cloth in the open. Generally only very small colonies of honey-bees have been used, and either small colonies or single individuals of humble-bees.

The great disadvantage of using honey-bees is the high mortality rate, resulting partly from the artificial nature of the environment in which they are made to work (particularly under glass) and partly from the difficulty of adjusting the size of the colony to the small number of flowers available as sources of nectar and pollen.

Attempts have been made over the past three years to devise a technique which would use queen-right colonies and would allow the bees to lead as normal an existence as possible and yet be available for pollination work when required.

Cages made of nylon screen supported on a metal framework had been used by one of us (C.G.B.) for producing seed of red clover. The cage measured 9 ft. $\times$ 9 ft. $\times$ 7 ft. high. Outside the cage and near one corner, a hive of bees was placed on a low stand and a tunnel led from the entrance of the hive through a sleeve attached to the cage.

This apparatus was used at N.V.R.S., Wellesbourne, in 1953 to pollinate brassica plants. A good set of seed was obtained but proper development of the colonies did not occur because the number of plants per cage was too small to support so many bees. It was then decided that the bees should be allowed free range at intervals during the flowering of the brassica crop, on the assumption that during the night, in the hive, the foraging bees would be thoroughly cleansed of all pollen collected during the previous day's flying. By this method of alternate confinement and free range, it was hoped that the shortage of food inside the cage would not seriously harm the colony if its members could forage during the following period of free flight.

This assumption was tested in 1954. The tunnel connecting hive and cage was modified so that the bees could either be directed into the cage or allowed free range. Inside the cage were planted 16 Brussels sprouts plants and several dozen plants of white varieties of radish. Within a few yards to the south of the cage was a bed of plants of red varieties of radish and 100 yards away, also to the south, was a large plot of spring cabbage. The bees were alternately confined and allowed free flight for periods which varied with the availability of flowers in the cage.

When the bees were confined to the cage, some of them could always be seen resting on the inside surface of the nylon screen and casualties could be found on the

floor of the cage after each day's work, but the casualties were greatest when the colony was newly confined and after a few days the numbers were not serious.

Hybrids between red and white radish would be identified by the red colour contributed by the male parent, and hybrids between Brussels sprouts and spring cabbage would be easily recognized by their general growth and development. Radish and Brussels sprouts are not inter-fertile. Seed was collected from the Brussels sprouts and white radish plants and was sown in the spring of 1955. No hybrids were found and hence there was no pollen contamination of either crop.

Plants were taken from the same field crop and seeded at the same time ; those pollinated by bees under nylon cages gave an average of 6·28 gm. seed per plant, and those pollinated by hand in a dutch-light structure gave an average of 3·00 gm. seed per plant.

As shown in Fig. 1, the hive is raised about one foot from the ground on a hive

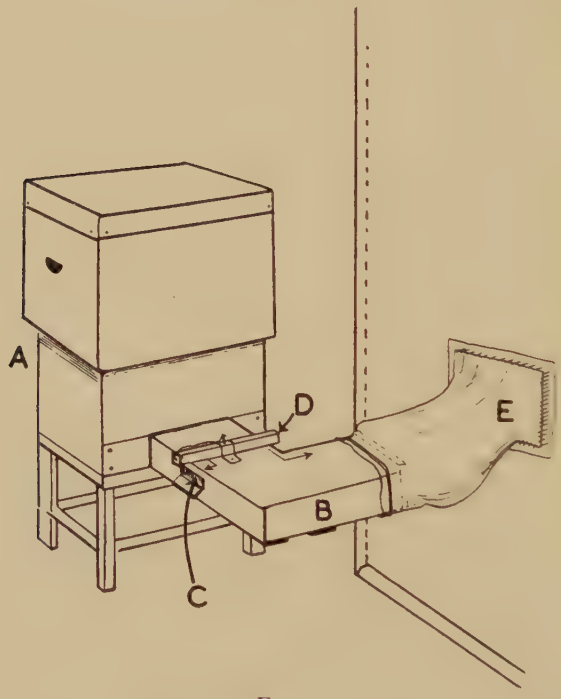

Fig. 1.

General arrangement of apparatus.
A, beehive on stand; B, tunnel; C, exit for free flight;
D, adjustable block; E, sleeve to cage.

stand and is placed outside the cage. This makes it simple to allow the bees free flight, leaves more room inside the cage for the seed crop, and allows the beekeeper to manipulate the colony without difficulty.

One end of the entrance tunnel is securely attached right across the entrance of the hive and the other end communicates with the cage by means of a canvas sleeve which is sewn into the cage wall. Care must, of course, be taken to ensure that the

tunnel is attached both to the hive and to the cage in such a way that the bees cannot escape.

The entrance tunnel is designed for attachment to a British Standard National Hive. Its construction is shown in Fig. 2. It should be made from well-seasoned

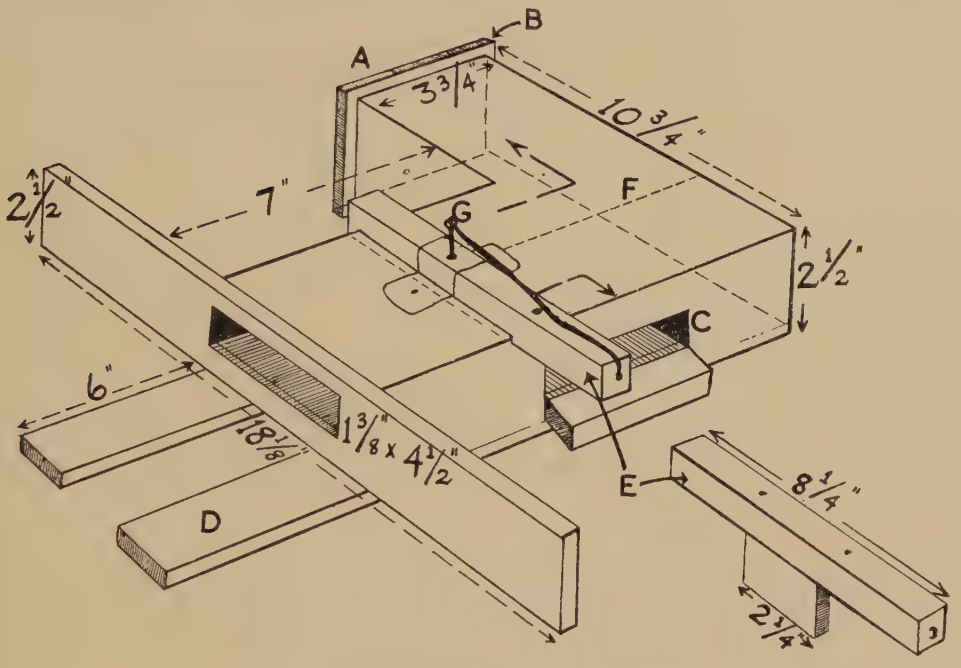

Fig. 2.

Detailed structure of tunnel.

A. Entrance to cage. B. ½-inch flange to retain cage sleeve. C. Exit for free flight. D. Attachment to underside of floor board of hive. E. Adjustable block to open compartments to A or C. F. Fixed partition below this line. G. Pin to fix adjustable block.

hardwood and care should be taken to ensure that the slide (the positioning of which allows the bees either to enter the cage or to fly in the open air) fits fairly loosely so that it does not jam even if the wood swells slightly.

The hive and tunnel having been placed in position, one can manipulate the slide so as to divert the flying bees either into the cage or into the open air, without risk of being stung. Changes from free flight to flight in the cage and vice versa should always be made in the evening or early morning when all bees are in the hive.

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VIRUS DISEASES OF CHERRY TREES IN ENGLAND

II. GROWTH SUPPRESSION CAUSED BY SOME VIRUSES

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THE first paper in this series described the virus diseases of cherry trees found in English orchards by indexing (virus-testing) trees with and without symptoms (Posnette, 1954). Little information was then available on the effect of these diseases on growth and cropping so that, although some were known to be prevalent, their economic importance could not be assessed.

The effect of these virus diseases on cropping cannot be estimated accurately until two field experiments, started in 1953 on this Station, have continued for several years. Their effect on growth has now been determined, however, in two trials to be described in this paper.

MATERIAL AND METHOD.

The mazzard clone F12/1 was used as the test plant ; rooted layers were selected for uniform size, and planted 6 ft. apart for Trial 1 and 3 ft. apart for Trial 2. They were inoculated by patch-grafting, the scions being taken from a source previously tested and known to be infected with one of the following viruses :

Rugose mosaic. This virus, previously described as cherry rosette virus (Posnette, 1954), produced symptoms on Napoleon, Lambert and Bing more like those of rugose mosaic (Thomas and Rawlins, 1951) than those of mottle leaf (Reeves, 1941).

Rusty mottle. The " isolate " used in Trial 1 was that causing the vein yellowing and red mottle previously described ; the one used in Trial 2 caused large necrotic spots on the leaves of F12/1, in addition to the rusty mottle. These necrotic spots were probably not due to necrotic ring spot virus, as no reaction indicating this occurred when buds from this source were inserted in Shirofugen (*Prunus serrulata*) trees.

Tatter leaf. The tatter leaf virus caused severe necrosis mainly of the leaves on the fruit spurs and at the base of extension shoots. Necrotic areas rarely developed on leaves formed in summer. Leaf symptoms were much more severe in the first year after inoculation than in later years, when only scattered necrotic spots developed. The virus is probably a virulent strain of necrotic ring spot virus as it caused a severe reaction in Shirofugen and peach. Indexing on Montmorency caused sour-cherry yellows.

Rasp leaf or Pfeffinger. The source of this virus was a tree (var. Frogmore) in an orchard in north-east Kent. Symptoms induced on Bing sweet cherry were typical of rasp leaf as described by Bodine and Newton (1942), but leaf enations have gradually become less conspicuous during the six years that the inoculated trees have been under observation. Indexing on mazzard F12/1, Bing, Hedelfingen and Napoleon,

and comparison with other sources of enation-causing viruses of *Prunus* have led to the conclusion that this virus is probably identical with that causing Pfeffinger disease in Switzerland (Blumer, 1950) and Eckelrader disease in Holland (Mulder, 1951).

Necrotic line pattern. This virus was collected from an orchard in Herefordshire ; similar though apparently more virulent strains have been found in Kent. The symptoms differ from tatter leaf in that lines or rows of necrotic spots appear on the leaves of the extension growth formed throughout the summer.

Ring mottle. This virus causes a faint ring or oak-leaf pattern on the leaves of many sweet cherry varieties ; it differs from viruses in the necrotic ring spot group in causing no symptoms on sour cherry, peach and Shirofugen.

Trial 1.

Trial 1 commenced in April 1952, when six two-year-old F12/1 plants were inoculated with each of the six viruses already mentioned. The treatments were randomized, with fifteen control plants grafted with bark from healthy F12/1. The trees were measured each winter until 1955–6, when five infected with each of the viruses and ten controls were cut off at ground level and weighed.

As shown in Fig. 1, each of the viruses reduced the growth of the cherry trees to about the same extent in each successive year ; in proportion to the growth of healthy trees, the reduction varied from 15 per cent. (by weight) caused by ring mottle to 50 per cent. by tatter leaf and rasp leaf viruses (Table I and Fig. 2).

Table I.

Trial 1. Effect of cherry viruses on the size of F12/1 plants four years after inoculation, expressed as percentages of the control plants.

Virus	Height	Girth (12 in. above soil)	Weight
Control	100·0	100·0	100·0
Ring mottle	92·6	90·3	85·4
Rusty mottle	92·4	83·6	74·0
Necrotic line pattern	88·5	78·5	59·7
Rugose mosaic	81·9	75·2	55·7
Tatter leaf	84·0	72·7	50·9
Rasp leaf	74·2	69·4	42·6

Means bracketed together do not differ significantly at P=0·05.

A notable feature of this experiment was the uniformity in weight of the control plants in contrast with the variation in some of the virus treatments. The variation (Table III) was that occurring four years after two-year-old plants had been inoculated and is unlikely, therefore, to be due to differences in the amount of virus inoculated.

Trial 2.

Trial 2 was not planned to measure growth effects, but was an outcome of indexing 24 trees of the variety Early Rivers and 33 of Turkey Heart by inoculating

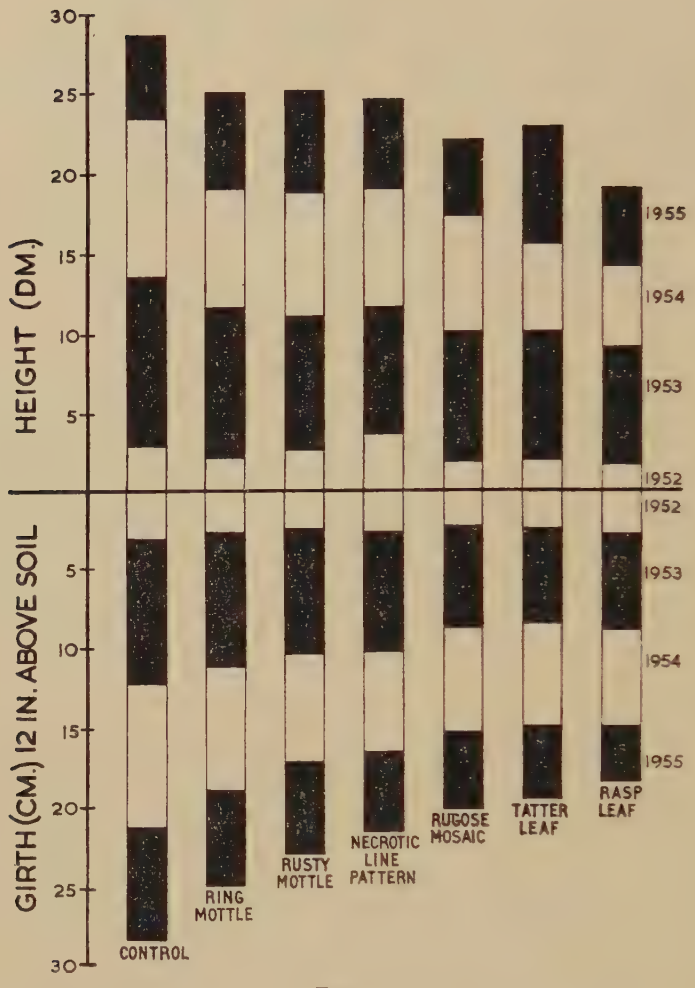

FIG. 1.

Growth (height and girth) of F12/1 plants after inoculation with different viruses.

three plants of F12/1 with scions from each tree in July 1953. The Early Rivers were infected with ring mottle and the Turkey Heart trees with rusty mottle, so that 72 F12/1 plants infected with the former and 99 infected with the latter virus (randomized in sets of three) were available for comparison with 18 uninoculated controls. The plants were measured two growing-seasons (30 months) after inoculation (Table II), and the reduction of growth (height and stem girth) on the infected plants, compared with the controls, was greater than that which occurred with the different ring mottle and rusty mottle isolates used in Trial 1.

DISCUSSION

Both trials have shown that two of the viruses most prevalent in England, ring mottle and rusty mottle, depress the growth of mazzard F12/1 by at least 15 per cent.

PLATE I

Fig. 2.

F12/1 plants, 4 years after inoculation.
a. Necrotic line pattern; weight, 28·4 lb.
b. Rasp leaf; weight, 22·4 lb.
c. Control; weight, 51·6 lb.

[*face p. 300*

Table II.

Trial 2. Effect of ring mottle and rusty mottle on height and girth of F12/1 plants, 30 months after inoculation.

Virus	Height		Girth (9 in. above soil)	
	dm.	per cent.	cm.	per cent.
Control	30·9	100·0	14·0	100·0
Ring mottle	23·9	76·7	10·6	75·7
Rusty mottle (necrotic strain)	24·1	77·3	10·7	76·4

The control plants differed from the inoculated plants at P=0·001.

and 25 per cent. respectively (by weight). The greater effect of the rusty mottle isolate used in Trial 2 is probably due to its being a more virulent type than that used in Trial 1 ; alternatively the necrotic leaf spot, by which the Trial 2 isolate could be distinguished, may have been caused by a contaminating necrotic ring spot virus, although no evidence to support this was obtained by indexing. The ring mottle isolate in Trial 2 was also more severe in its effect than that used in Trial 1.

The viruses which have an obvious effect on orchard trees, viz. rugose mosaic, tatter leaf and rasp leaf (or Pfeffinger), retarded the growth, estimated by weight, of the F12/1 plants by 44 per cent., 49 per cent. and 57 per cent. respectively. The effect of rasp leaf was unexpectedly severe. Although this was regarded as the most virulent cherry virus known in Europe before the discovery of leaf roll (Posnette and Cropley, 1955), F12/1 was known to develop less conspicuous symptoms than several scion varieties in commercial use, such as Roundel, Napoleon, Frogmore, Hedelfingen and Bing.

The clone F12/1 was used primarily because it was the only one of which a large quantity of virus-free material was available in 1951 and, as it is propagated by layering, plants of uniform size could be obtained readily from established stool-beds. It is the only clonal rootstock widely used for cherries, and the response of F12/1 to virus infection may well be reflected in the many commercial orchards now planted entirely with trees on this stock. Although F12/1 develops clearer symptoms of infection with most cherry viruses, it does not seem to be affected by them to any greater extent than are most varieties of which we have attempted to find virus-free material. Differences observed between the growth of healthy and virus-infected trees of Early Rivers, Amber, Bradbourne Black and Merton Bigarreau, for instance, have been of the same order as those found with F12/1. The most obvious result of infection with necrotic ring spot in nursery plants has been a reduction in branching rather than in height, as found by Millikan (1955) with Montmorency sour cherry.

Rasp leaf and tatter leaf viruses were very variable in their effects, and trees infected with each of the six viruses were less uniform in size than the controls (Table III). This difference between infected and virus-free trees has been noticed among nursery trees of commercial varieties, not only with cherry but also with apple trees (Posnette and Cropley, 1956). Uniformity in tree size is one of the main advantages claimed for the use of clonal as compared with seedling rootstocks, but this uniformity cannot be fully attained with virus-infected plants, even when they

TABLE III.

Effect of cherry viruses on the uniformity of clonal plants of mazzard F12/1.

Virus	Difference between largest and smallest plants, log weight (lb.)	S.E. of mean (logs)
Control 1	0·067	0·011
Control 2	0·077	0·013
Ring mottle	0·113	0·019
Necrotic line pattern	0·145	0·027
Rugose mosaic	0·144	0·029
Rusty mottle	0·170	0·032
Tatter leaf	0·234	0·039
Rasp leaf	0·251	0·048

are uniformly infected with one virus. Most nursery trees of the cherry varieties that we have tested were not uniform even in this respect.

SUMMARY.

Two experiments are described in which mazzard F12/1 plants were inoculated with the cherry viruses rugose mosaic, rusty mottle, tatter leaf, rasp leaf, necrotic line pattern and ring mottle. The height, stem girth and weight of the control plants were significantly greater than those of the plants inoculated with each of the six viruses. The reductions in plant weight, four years after inoculation, ranged from 15 per cent. (ring mottle) to 57 per cent. (rasp leaf). The weights of the plants infected with each of the viruses were more variable than those of the control plants.

ACKNOWLEDGMENTS.

The authors are indebted to Mr. G. M. Jolly and Mr. G. H. Freeman for the statistical analyses, and to Mr. E. Yoxall Jones for the photographs.

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ORCHARD TREE SPACING IN RELATION TO WIND AND CROPPING

By A. P. PRESTON
East Malling Research Station

THE magnitude and variation of the wind in some widely differing orchard sites in Kent has already been studied (Preston, 1952). This paper considers the relationship between the run of the wind* and the cropping of young apple trees on M.II planted at 25½ ft. square in two adjoining 10-acre plots, one with an interplant of trees on M.IX (high density plot) and the other with no interplant (low density plot).

SITE AND MATERIAL.

The orchard is on nearly flat land on an exposed hilltop site, just below the 500 foot contour, approximately one mile north of Charing Hill in Kent. The plantation was described as site F in the previous paper (*loc. cit.*). The low density plot contained 17 rows of Cox's Orange Pippin, 5 rows of Worcester Pearmain and 2 rows each of Sunset and Laxton's Fortune, all on the vigorous rootstock M.II and spaced at 25½ feet square. There were 26 trees in each row, making a total of 676 trees. The high density plot had, in addition to similar trees on M.II, an interplant of the same varieties on the dwarfing rootstock M.IX, there being three filler trees to each permanent tree. This gave a spacing of 12¾ feet square and a total of 2,576 trees. Fertilizers were applied at standard rates per tree. There were no windbreaks near the two plots and both were equally exposed to south-westerly wind. The trees were seven years old when the experiment began in 1952.

Anemometers.

One cup counter anemometer (Meteorological Office, Mk. II) was erected in the centre of each ten-acre plot in 1953 just before blossoming began. During the next two years two of these were used on each plot to ensure greater accuracy. The cups were 4½ feet above ground, i.e. at approximately the same height as the centres of the heads of the trees on M.II. The anemometers were calibrated in an open field before and after each experiment, as in the previous study (Preston, 1952).

RESULTS.

Run of wind during and after blossoming.

Records made during the blossom period, and also for some time afterwards when the trees were in full leaf and making shoot growth, showed consistently more wind passing through the trees on the low density plot than through the high density plot. The increase in the run of the wind on the low density plot varied from year to year, from 21 to 37 per cent. during the blossom period and from 28 to 44 per cent. in the post-blossom period (Table I).

The difference between the two anemometers on the same plot was under 5 per cent. during any one experiment.

* Wind-flow past a given point during a period of time.

TABLE I.

Wind ; percentage increase on low density plot over high density plot.

Year	1953		1954		1955	
Blossom period	22·2	(14)*	21·4	(17)	37·7	(20)
Post-blossom period	28·7	(17)	31·9	(45)	44·4	(13)

* Number of days.

Fruit yield.

The fruit yield from trees of all four varieties on M.II provides a striking contrast between the trees on the high and low density plots. The first crop in 1952, the year before the wind study began, was a light one. The increase in yield from the trees on M.II on the high density plot has been consistent for all varieties ; no variety in any year yielded more heavily on the low than on the high density plot. The percentage increase in yield is shown for three varieties in Table II ; that for Laxton's Fortune has been omitted owing to the relatively small crops and irregular bearing.

TABLE II.

Fruit yield per tree on M.II ; percentage increase on high density plot over low-density plot.

Variety	Number of trees per plot	Year				Increase over 4 years
		1952	1953	1954	1955	
Cox's Orange Pippin ..	442	209·8	62·8	67·6	60·9	82·3
Worcester Pearmain ..	130	71·4	21·8	18·8	33·3	28·8
Sunset	52	113·3	63·3	33·3	58·7	86·7

These figures refer solely to the trees on M.II, which are uniformly spaced on both plots. There were no obvious differences in the amount of blossom between the trees on M.II on the two plots. Excluding trees of Laxton's Fortune, the increase in total crop over the four-year period was 69 per cent. from trees on the high density plot. The actual total yields were 2,886 lb. and 4,880 lb. per acre from trees on the low and high density plots respectively. The yield from the filler trees on M.IX of the same varieties in the high density plot has, over the same period, added to the productivity of that plot by some 7,988 lb. of fruit per acre.

Tree size.

There being only one replicate of each plot, it was important to consider whether a gradual soil change had resulted in such a difference in tree size between the two plots as would account for the large differences in yield. Trunk girth measurements were made during the winter of 1955 on two trees, selected at random, in each row on both plots. An analysis of variance was carried out on the data from the Cox's Orange Pippin trees ; this showed that the trees on the high density plot were 10 per

cent. larger than those on the low density plot. The mean trunk girth figures (cm.) were :

High density plot	*Low density plot*	
28·0	25·5	(P <0·01)

Parallel regression lines were worked out for the two sets of data and the mean residual variance about the two lines was compared with the corresponding residual variance on getting a single regression line to the entire data. The same regression line did not fit the two sets. The sudden reduction in tree size on going from the high density plot to the adjacent low density plot is strong evidence against the reduction being due to a soil gradient.

Measurements made in spring 1956 on the centre tree of each row of Cox's Orange Pippin on M.II showed that the mean height and spread of trees on the low density plot was 8·6 × 10·8 feet, and on the high density plot, 9·5 × 10·1 feet. The smaller spread of the latter is probably due to " siding up " to allow room for the fillers.

Thus the trees on the high density plot were in fact slightly larger than those on the low density plot, but this difference could in no way account for the large increase in crop from trees on the high density plot.

DISCUSSION.

Opinion is largely divided at present upon the advisability of planting filler trees among bush apple trees. Wide tree spacing, without fillers, tends to make cultivation, gang-mowing and mobile spraying easier but, as this paper has shown, the crops during the first ten years from widely spaced trees may be far below those from similar trees that are interplanted with other apples, quite apart from the additional crops from the filler trees. Furthermore, although the costs of establishment per acre rise as the density of tree planting becomes greater, Butler (1950) has pointed out that they do not rise as rapidly as the increase in tree numbers.

In these experiments the degree of shelter provided by the filler trees on M.IX, expressed in terms of miles run of wind passing through the plot, is somewhat surprising in view of the relatively small size of these trees ; they were approximately 6·3 feet high and 6·5 feet across in spring 1956. An even higher degree of " natural " shelter might be possible by using a single filler tree on M.II in the centre of a 25½ feet square, thus reducing the number of trees required and the eventual cost of thinning.

The causes of the different cropping of the two sets of trees on M.II are undoubtedly complex. Firstly, the wind effect may have been a direct one, affecting the setting of the blossoms and fruit drop by lowering the temperature. Modlibowska (1945) has shown that lower temperatures reduce pollen tube growth. Secondly, the increased wind probably increased the laceration of the foliage ; this laceration was frequently observed in the orchard and it may have affected tree growth and so accounted for the smaller trees on the low density plot. Thirdly, the effect may have been an indirect one, through pollinating insects working more among the sheltered blossoms of trees on the high density plot and thus increasing the chances of securing cross-pollination between varieties.

The trees are now approaching maturity and the filler trees on M.IX on the high density plot will soon have to be grubbed, if drastic pruning of the trees on M.II to accommodate the fillers is to be avoided. The evidence shows that the filler trees have not had a detrimental effect upon the development and cropping of the trees

on M.II ; indeed, under the conditions of this trial, their presence seems to have been beneficial. Thus, under these exposed conditions, the higher tree density per acre provided by an interplant has both lessened the run of the wind and increased the yield of the permanent trees, quite apart from the additional yield from the filler trees themselves.

SUMMARY.

Two plots, each of ten acres, on an exposed hilltop orchard site in Kent, were planted in 1946 with trees of Cox's Orange Pippin, Worcester Pearmain, Sunset and Laxton's Fortune apples on M.II at 25½ feet square. One plot had, in addition, an interplant of three filler trees of the same varieties on M.IX to each permanent tree on M.II, giving a tree spacing of 12¾ feet square.

Wind records, with calibrated cup counter anemometers, were made on the two plots during and after the blossom period in the years 1953–55. The run of the wind was greater on the low density plot each year ; from year to year the percentage increase during the blossom period varied from 21 to 37, and during the post-blossom period from 28 to 44 per cent.

The fruit yield per tree up to 1955 for three varieties on M.II was 69 per cent. greater on the high density plot. The filler trees on M.IX further increased the productivity of this plot by 7,988 lb. of fruit per acre.

Trunk girth measurements on random sample trees of Cox's Orange Pippin on M.II showed that those on the high density plot were 10 per cent. larger. Regression lines worked out for the two sets of data provided strong evidence that the difference in tree size was not due to a soil gradient.

These results are discussed in relation to tree spacing generally. Under the exposed orchard conditions of this trial high density planting, using filler trees on M.IX, reduced the run of the wind and increased the size and yield of the trees on M.II in their early years.

ACKNOWLEDGMENTS.

This study would not have been possible without the willing co-operation of the growers concerned, Messrs. Tom Neame and Christopher Neame, to whom the writer extends his best thanks. Also to Mr. Jack Cronk, resident manager at the farm, for his careful recording of the anemometers and the blossom period. The Statistics Section of East Malling Research Station assisted the writer in planning the calibration trials for the anemometers and undertook the analyses of variance.

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BOOK REVIEWS

THE FRUIT YEAR BOOK. 1956. (London : The Royal Horticultural Society. 1955. Pp. 164, illus. Price 10s.)

The Fruit Year Book for 1956 presents its usual varied bill of fare, ranging from more serious articles to those in lighter or pleasantly reminiscent vein, such as Sir Stephen Tallents on the Sir Isaac Newton Apple and L. F. Clift on Fruit Growing in the West Midlands.

Though intended primarily for the amateur, the Year Book includes articles of interest to the scientist. Chief among these is that by Dr. A. H. T. Robb-Smith, who gives a comprehensive account of the Blenheim Orange apple, and its variants and seedlings ; a good deal of thought and research has obviously been put into it, and it merits careful reading. A. Gavin Brown stresses the possible importance of bud sports in fruits and makes a special plea for keeping a careful look-out for these and, where they seem to possess some desirable character, for bringing them to notice. Drs. G. H. L. Dicker and A. H. M. Kirby give some impressions of apple orchard practices in Canada, arising out of a three months' visit there in the summer of 1954. The main interest in their article lies in an account of the attempt started in Nova Scotia to control pests by natural agents. They discuss the results to date and the possible application of the method to other parts of Canada and to England. The authors have managed to pack quite a bit of valuable information into this article.

Of more practical interest to the amateur, A. P. Preston writes on the shaping and pruning of bush apple trees. He shows that, in recent experiments at East Malling, regulated and renewal pruned trees have in their early years cropped more heavily than established-spur pruned trees. It seems quite possible that both these methods may prove of value in the garden, but, where adopted, increased risk of Apple Mildew must be faced. A. Taylor and M. G. Ridpath, of the Ministry's Infestation Control Division, review the damage done by birds to buds and fruit, and describe some of the devices used to combat it. They have to confess, however, that no simple or satisfactory means of protection has as yet been devised. But it is good to know that research is in progress, and it is to be hoped that in due course a practical remedy will be found. H. L. Jaquier, in " The Fruit Tree Episode ", gives a racy account of his vicissitudes in establishing a fruit garden. Much can be learnt by the beginner from an account of this sort, even if much, perforce, remains unsaid. The same can be said of the accounts of a Brains Trust and a discussion on the training of raspberries and apples.

More specialized articles are by S. J. Jesse, who puts forward the claims of grapes for those who can afford a small greenhouse and can spare the necessary time and trouble ; and by J. H. Walker and Miss Gwendoline Couch, who in much the same way deal with the growing of fan peach trees. Both articles are clearly and concisely written.

Howard Crane quotes Francis Bacon on apples. Though not all the methods of storage mentioned would commend themselves to the modern grower of fruit, it would seem that he anticipated the " emulsified dip ", and with his apples " shut in a Box " was he thinking of the possibilities of gas storage ?

It is as well to have on record an account, by Miss Muriel Smith, of the impressive

exhibit staged by the National Fruit Trials, Wisley, at the Autumn Show in October 1954, to demonstrate the classification of apples. Miss P. Rowe-Dutton gives useful comments on some recent fruit literature.

Last but not in any way least it is pleasant to see this year's volume dedicated to Professor B. T. P. Barker, for so many years Director of Long Ashton Research Station and so well known for his work on fruit, and particularly on cider. It is a well-deserved tribute.

To sum up—all the articles are carefully and thoughtfully written and the volume is well illustrated, though one misses perhaps the colourful covers of the past, but maybe this is a matter of expense. There is an index, which is always useful. The only criticism one might make is that the Year Book would seem to be tending to cater rather for the more knowledgeable grower of fruit, and even for the commercial fruit grower. If it is desired to attract and retain the interest of the less knowledgeable amateur who has only limited time and means at his disposal, it may be that his needs will have to receive more consideration.

A.C.P.

THE RHODODENDRON AND CAMELLIA YEAR BOOK. 1956. Pp. 167, illus.
THE DAFFODIL AND TULIP YEAR BOOK. 1956. Pp. 142, illus.
THE LILY YEAR BOOK. 1956. Pp. 163, illus.

The Royal Horticultural Society. (London. 1955. Price 10s. each.)

Each of these publications gives the impression of having been produced by enthusiasts, and the reader is soon infected by their enthusiasm. Most of the contributions are directed to the expert amateur or professional grower, but many points of scientific interest can be found.

Articles on camellias now provide a substantial part of the Rhododendron and Camellia Year Book, reflecting their new and growing popularity. There are fascinating accounts of several famous rhododendron and camellia gardens, by distinguished specialists. A useful article on the frost hardiness of camellias is provided by Mr. L. S. Fortescue. Dr. J. S. Yeates gives further notes on tip grafting rhododendrons. Some suggestions are put forward by an expert committee for revised and standardized practice in the naming of rhododendron hybrids. Lord Digby mentions that where rhododendrons have died from *Armillaria mellea*, magnolias planted in the same spots have always survived.

The Daffodil and Tulip Year Book is dedicated to Mr. F. A. Secrett, and those who have always associated his name primarily with vegetable growing will be interested to read that he grows 40 acres of daffodils and tulips. Mr. Secrett himself contributes an article on the commercial development of daffodils during the last 50 years, much of which has been due to the successful application of scientific research. Other papers include notes on raising daffodil seedlings, on scent in daffodils, and on control of bulb fly damage. The results of a ballot, by 25 experts, on the best daffodils for various purposes will help those who are confused by the plethora of varieties now available.

The Lily Year Book includes an illustrated paper by Rear-Admiral P. Furse on the genus *Fritillaria*, and a report of a Lily Group discussion on these beautiful plants. A paper on the cultivation of lilies by Mr. L. Tuffery includes notes on their root growth.

All of these Year Books provide interesting and stimulating reading.

W.S.R.

BACKGROUND TO BEEKEEPING. By Allan C. Waine. (London : W. H. & L. Collingridge Ltd. 1955. Pp. 120, illus. Price 15s.)

This is a beginner's book on beekeeping. Although this subject is still only a hobby to the author after twenty-three years, he is nevertheless a qualified lecturer and examiner in the craft of beekeeping. The book is divided into eleven chapters and it is encouraging to note that only one chapter is devoted to " troubles ". A glossary of terms which is referenced to the text, an index, and a list of addresses of manufacturers of beekeeping equipment complete the book.

This is an admirable book for a beginner and should help him over the first two years of this exciting hobby. Thereafter the beekeeper should be in a better position to judge for himself which of the many methods of swarm control and hive management he should adopt under his particular conditions. He is greatly helped in this respect by the generous list of suggestions for further reading at the end of each chapter.

A.P.P.

SOIL STERILIZATION. By W. J. C. Lawrence. (London : George Allen & Unwin Ltd. 1956. Pp. 171, illus. Price 18s.)

Most growers of glasshouse crops will be familiar with at least some of the processes used to partially sterilize soil, of which steam is the most important and successful. The reasons for this success and the many ways in which the system may be made more efficient and economical are not so well known, and herein lies the importance and usefulness of Mr. Lawrence's explicit book.

One of the facts which will be a revelation to many users of steam as a sterilizing agent will be the limited rate at which soil can absorb heat, and the remarkably low pressure necessary to allow for this rate of heat transfer without wasting steam. In the past, and even at the present moment, it is quite common to have the house and adjacent houses enveloped in steam which has escaped from the soil ; apart from the discomfort to workers under such conditions, it is uneconomic.

The importance of avoiding re-infection of partially sterilized soil through carelessness and unhygienic practices is rightly stressed, and in this connection it may be pertinent to mention that the sterilizing and mixing shed should not be used as an alternative means of entry to the potting shed or glasshouses ; in other words, the mixing and sterilizing shed should be a separate entity, otherwise it is practically impossible to keep the floor clean for mixing composts.

The effect of heat and its bearing on the growth of plant organisms in the soil are mentioned, and the important point that treatment of the soil is not an alternative to good culture is borne out by one of the many illustrations which help to emphasize some of the facts. The notes and illustrations on the various forms of sterilizers are most useful, especially those on the John Innes Low-rate Sterilizer, which is an efficient unit for the treatment of small quantities of loam. The use of electricity and chemicals is rightly reserved for the treatment of very small quantities or where it is impossible or uneconomic to use steam ; the choice of chemical depends to a large extent on the fungi and soil organisms to be controlled. New methods of using steam, as used on the Continent and the United States of America, are explained ; the system of using steam once in three years, which is practised in some parts of this country, may be a factor against the introduction of alternative methods, especially where a high capital outlay is necessary.

This book should be of great interest and importance to all growers of glasshouse crops who wish to improve soil conditions and crops, and the efficiency of one of the most expensive cultural treatments confronting the industry.

M.M.M.

THE BIOLOGY OF ROOT-INFECTING FUNGI. By S. D. Garrett. (Cambridge : University Press. 1956. Pp. 293. Price 30s.)

Whilst this book is not an instructional text for horticultural readers, the author's hope that it will arouse the interest of plant pathologists, and ecologically-minded biologists generally, is sure to be fulfilled. The book includes much of the subject matter contained in the author's earlier work " Root Disease Fungi " with certain aspects analysed in greater detail and the format considerably improved, although the first and introductory chapter dealing with antibiotic production and its possible significance in the biological control of root disease seems strangely isolated and misplaced. The following chapter summarizes most excellently the history of synecological studies of the soil fungal flora, continuing logically with a discussion of Waksman's concept of soil inhabitants and soil invaders. Other forms of classification of soil fungi are then mentioned and it seems unfortunate that Chesters' very useful and simple concept of local and wide colonizers is omitted. The bulk of the text deals with the parasitic growth habit, saprophytic behaviour and dormancy of root-infecting fungi and the epidemiology of root diseases.

Occasionally, in attempting to classify and characterize behaviour, the author is tempted to over-simplify : thus, in a discussion of *Verticillium* Wilt of hops, he contends (albeit rather hesitantly) that the mild strain is more highly evolved than the virulent on the grounds that it more nearly approaches a symbiotic relationship with this host. That such a conclusion is drawn from the behaviour of two strains of the pathogen on but one of their many hosts is hardly satisfactory.

Some of the concepts presented in " Root Disease Fungi " are discussed in greater detail and an attempt is made to define them more concisely. In doing so, the author has succeeded only in part ; in the act of definition the concept of " inoculum potential " has been extended rather than confined and some confusion with a newly-introduced term, " mycelial momentum ", may readily arise.

The very presence of these controversial subjects, however, increases, rather than detracts from, the value of this book—at once raising it above the level of a general textbook. The unwieldy wealth of literature concerned with root disease fungi has been collected, integrated and discussed to produce a book of immense value : more than a worthy companion volume to the " Root Disease Fungi ".

G.W.F.S.

CHROMOSOME BOTANY. By C. D. Darlington. (London : George Allen & Unwin Ltd. 1956. Pp. 186, illus. Price 16s.)

Professor Darlington is to be congratulated on having been able to condense this fascinating subject into a very readable account of only 186 pages. Experimental breeding and the study of chromosomes, which together make the foundation of genetics, have made it possible to bring the knowledge of wild and cultivated plants, of systematics, and of ecology into one focus. The aim of the book is to achieve this integration.

The first twenty-seven pages are devoted to the chromosomes themselves and this section includes an account of the occurrence, origin and adaptive value of B chromosomes. This general discussion on chromosomes might with advantage have been expanded, in the reviewer's opinion, particularly since it is now nearly twenty years since the last edition of Darlington's " Recent Advances in Cytology " was published.

The chapter on " Plants in Groups " delivers some shrewd blows at the systematists. Botanical classification has not been able to accommodate itself to the consequences of evolutionary change, so that it " continues to rest half-poised on the eighteenth-century fictions that the living world is inhabited by fixed species which exist . . . as ' types ' represented by original specimens in museums and . . . as ' varieties ' diverging from these types by some ineffable process of mutation ".

That chromosome studies have added an invaluable tool to the methodology of systematics is illustrated by reference to Babcock's classical work on *Crepis* ; the work of Skovsted, Harland, Beasley, and others on *Gossypium* would equally have served to illustrate this aspect.

The book gives a dynamic picture of evolutionary processes leading to speciation and to the formation of wider groups. Genes, chromosomes, and environment are regarded as three independent and mutually selecting variables. Chromosome ecology and geography are illustrated by maps showing the distribution of the different chromosome races of *Primula*, *Rhododendron*, *Buddleia*, *Leucojum*, *Oenothera*, and *Paeonia*.

Finally, the sections on plant breeding and on ornamental plants should prove of interest to most scientific horticulturists, and the book should be of value to all in the fields of cyto-genetics, plant breeding, and systematics.

R.L.K.

INDEX TO HORTICULTURAL ABSTRACTS. Volumes xxi-xxv, 1951-1955. Commonwealth Bureau of Horticulture and Plantation Crops, East Malling, Kent. (Obtainable from C.A.B. Central Sales Branch, Farnham House, Farnham Royal, near Slough, Bucks. 1956. Price 50s. or $7.)

The newest five-year index of Horticultural Abstracts, which runs to 368 pages, is " presented free to all lucky readers of H.A. Volume 25 ". It will be very welcome, particularly to those who, like the writer, have ever tried to find abstracts in past volumes in a library where no indexes were available. With its predecessors, even if they have to be bought, it is strongly recommended to all who are interested in the horticultural literature of the past quarter of a century.

T.N.H.

PUBLICATIONS RECEIVED.

REFRIGERATED STORES FOR FRUIT. Ministry of Agriculture Bulletin No. 159. (London : H.M. Stationery Office. 1955. Pp. 26, illus. Price 2s.)

WORLD CATALOGUE OF GENETIC STOCKS. RICE. F.A.O. Supplement No. 5. (London : H.M. Stationery Office. 1955. Pp. 13. Price 1s. 3d.)

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